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GEOPHYSICS

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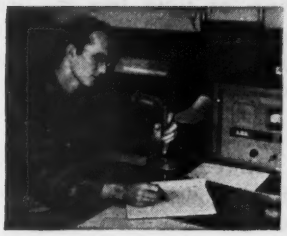

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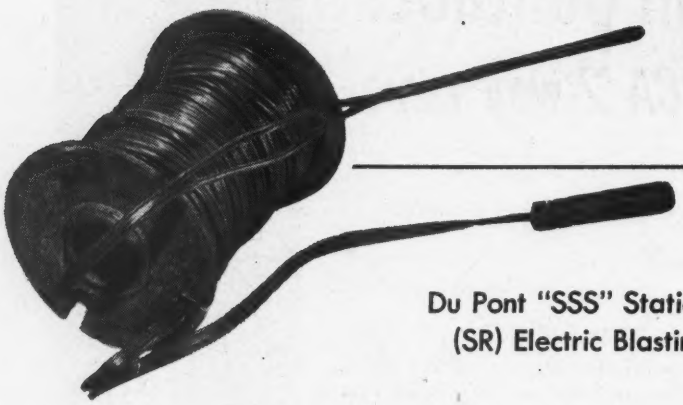

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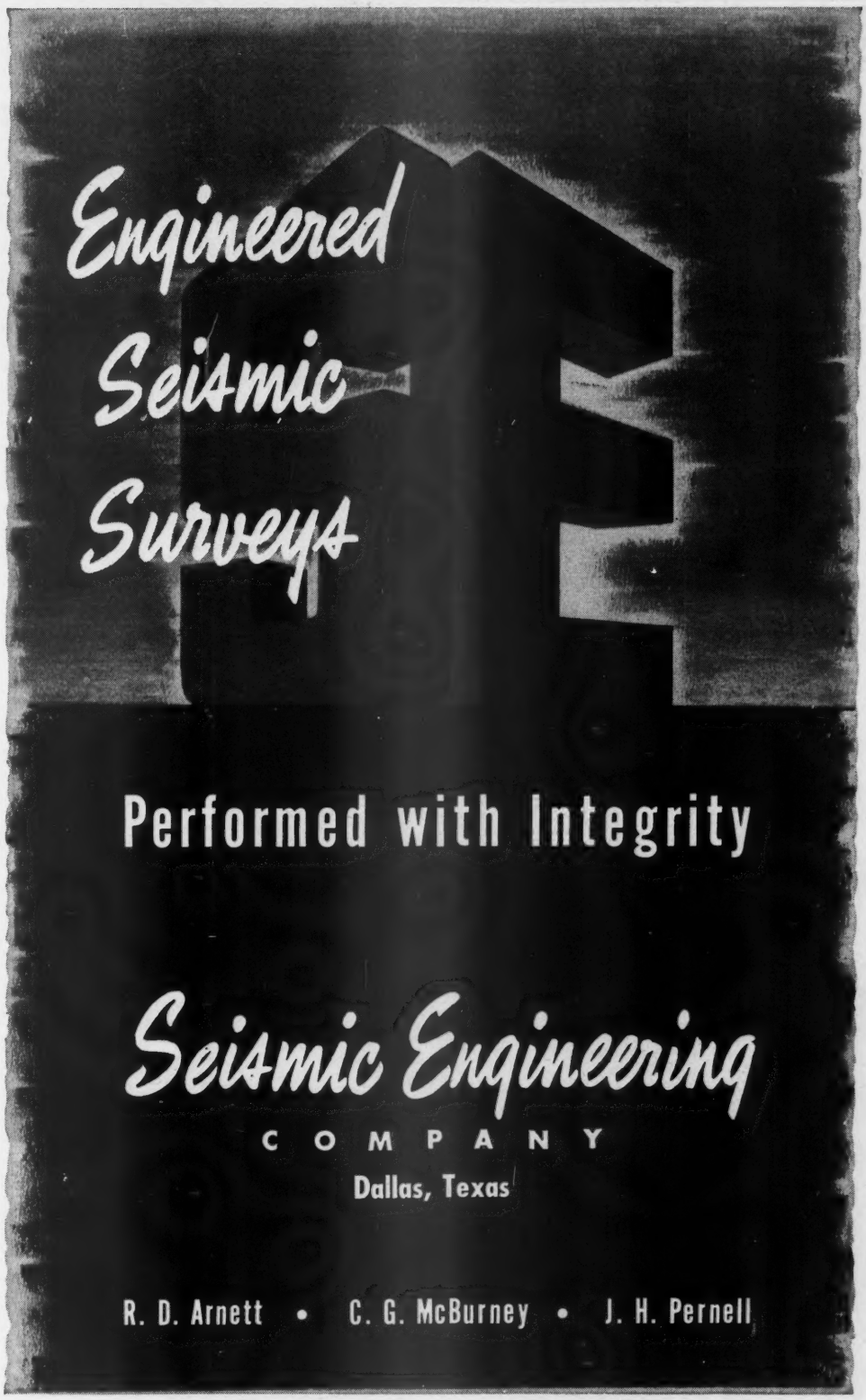
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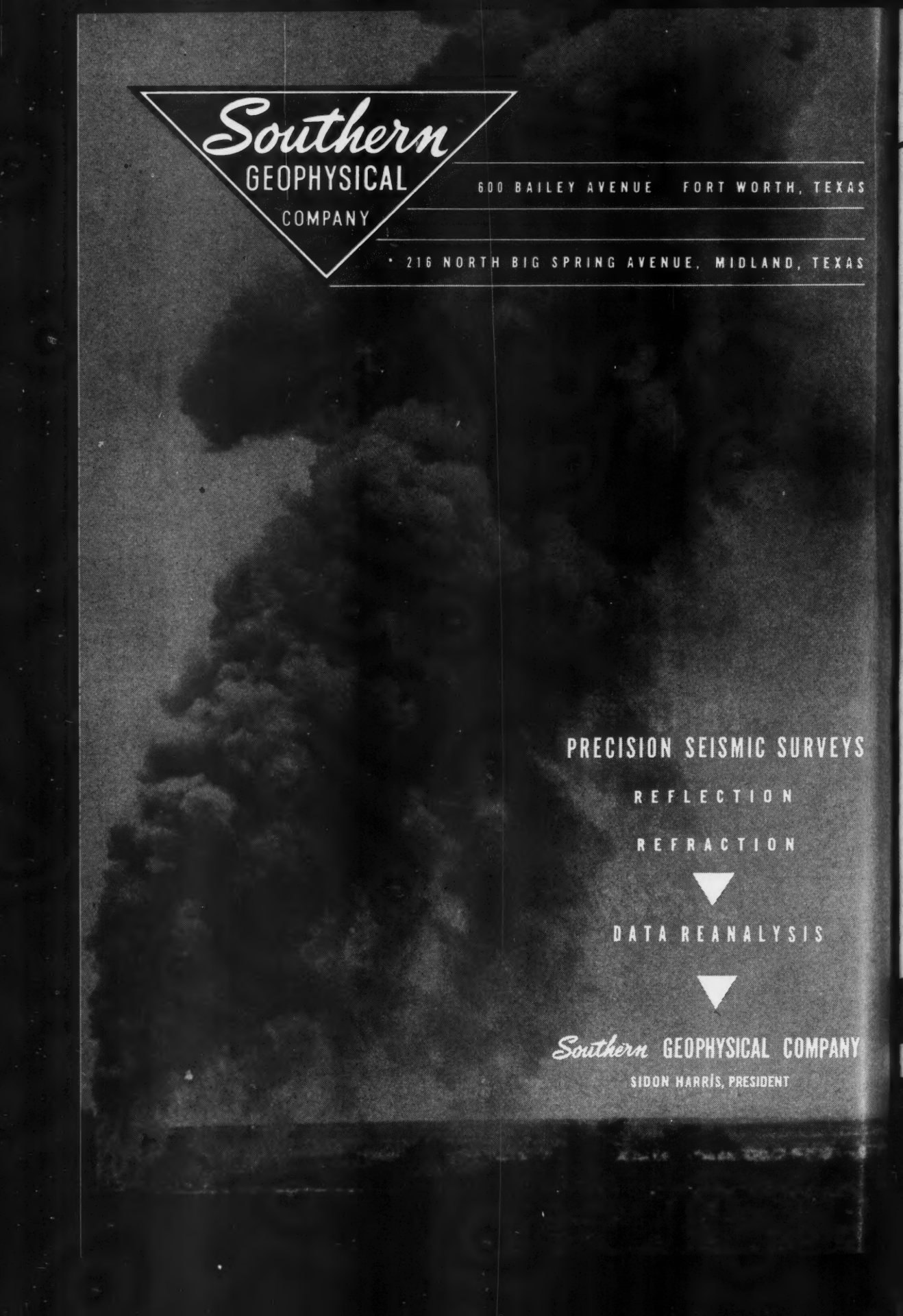
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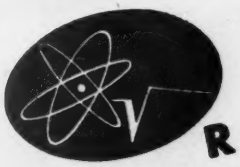

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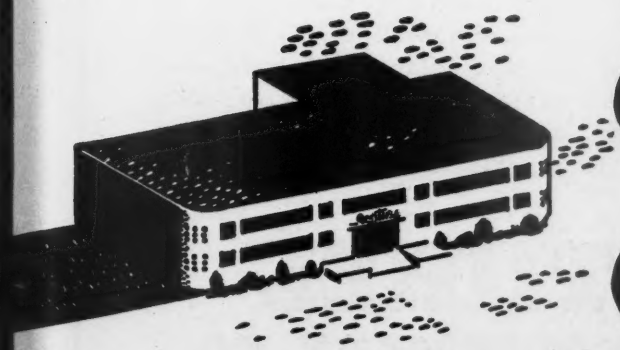

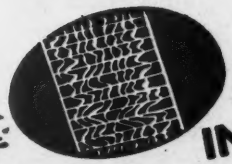

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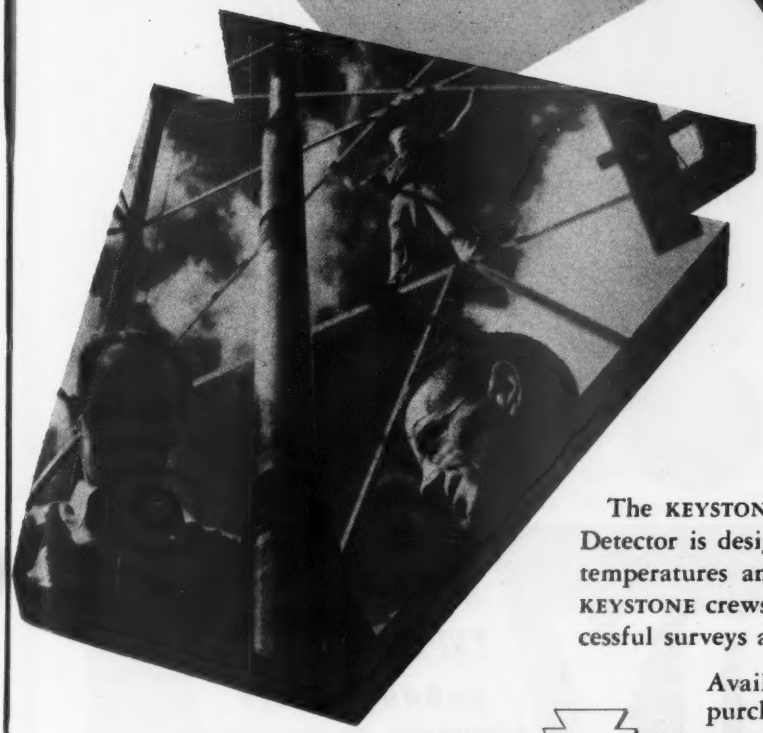

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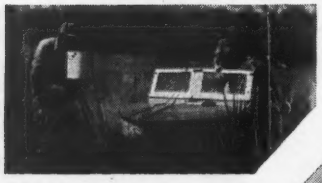

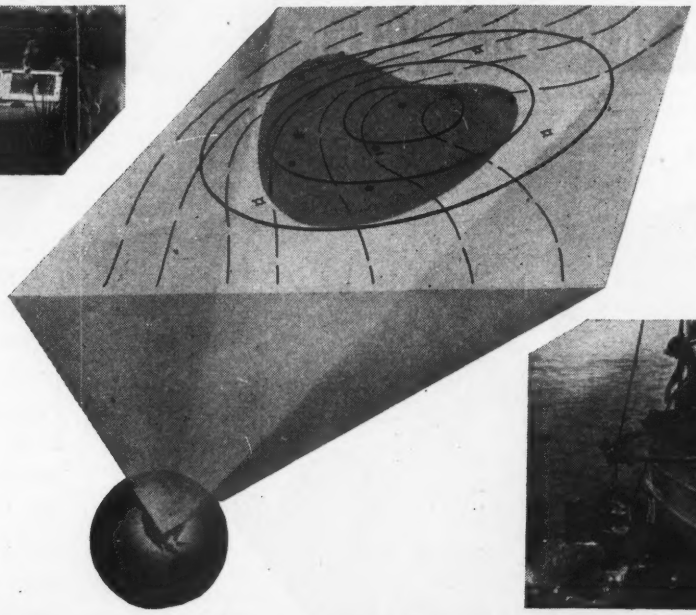

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VOLUME XVI JULY, 1951 NUMBER 3

GEOPHYSICS

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GEOPHYSICAL FRONTIERS*

GEORGE E. WAGONER†

In the years 1920 to 1940 there existed in the United States a vast frontier of undeveloped area to challenge geophysics. A great unexplored reserve of oil traps awaited the enterprising geophysicists who first brought their scientific devices to these strange lands. Through those early years, there was always new acreage for everybody interested; it was only necessary to stay away from, or keep ahead of, the competition. It was a lush period of easy, ready exploration. The geophysical frontier was the virgin area.

Geophysical prospecting for oil had started in the United States in the early '20's. The torsion balance found the Nash Dome in 1922, and the new-fangled refraction seismograph, used as early as 1921, resulted in the famous discovery of the Orchard Dome in Texas. The future king-pin of geophysics, the reflection seismograph, found the Maud pool of Oklahoma in 1927. The magnetometer was first used in the early '20's in the search for oil. Electrical methods were well advanced in the late '20's. Electrical logging started as early as 1927, and geochemical methods were developed in the '30's. The great race was on. In the first flush of the game, the bag was fabulous. Forty-four salt domes and structures were found in Texas in 1930 alone. Great oil companies were founded on these successes. Oklahoma was revitalized in the first great sweep of reflection parties. Illinois, long dormant, was kindled into a new oil area by the spreading exploration, and 200 new pools were found in the period 1936 to 1943. Kansas felt the impact as crews concentrated on its Barton Arch. Undreamed of structures in the old oil areas of Arkansas and Louisiana were dragged into man's knowledge by the probing geophysical tools. There eighty-five geophysical discoveries were made in the ten years following 1936. A similar campaign engulfed the California basins. The vast western plains of the country, last to fall, responded to the wiles of geophysics.

Today, this honeymoon is over. There are few new areas to beckon. Figure 1

* Address of Retiring President, Society of Exploration Geophysicists, presented at the joint meeting, A.A.P.G., S.E.P.M., and S.E.G., St. Louis, April 24, 1951. Manuscript received by the editor April 1, 1951.

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shows that a high percentage of the promising petroleum area of the United States has been shot. Some areas have been seismographed more than twenty times. The areas shown have been shot by many competing companies, and some areas have been shot and reshot by the same company. The repetition by the same companies has been caused by desire for closer coverage, engineering developments such as the automatic volume control, and new techniques. The repetition indicates that reserves have been overlooked, and that closer inspection is profitable.

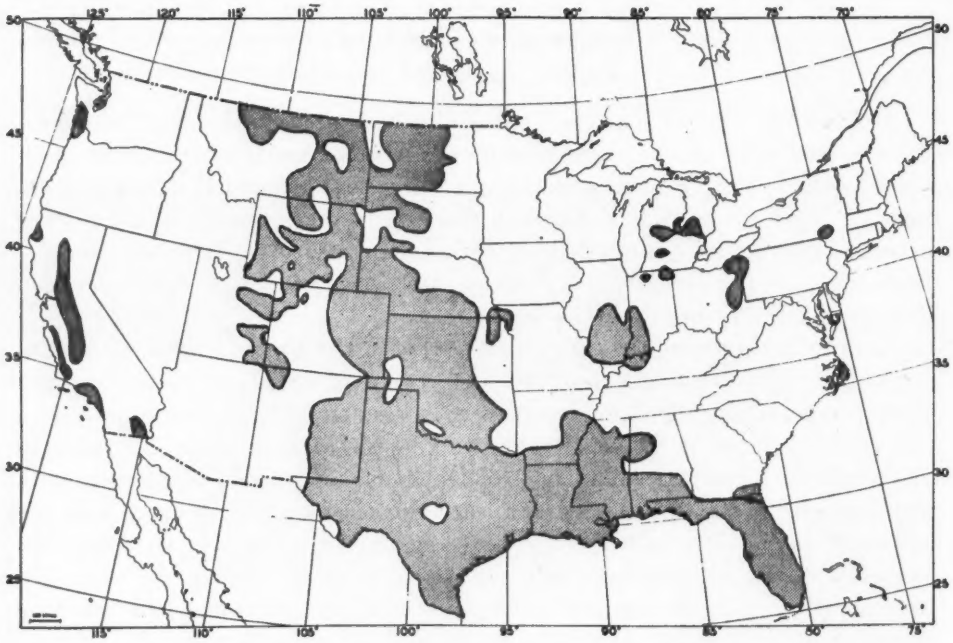

FIG. 1. Cumulative seismograph coverage in the United States.

But only a small amount of marginal virgin area remains. Is it all over for geophysics?

Obviously not. There are now more reflection parties operating in the United States than ever before. The membership of the Society of Exploration Geophysicists has grown to 2,700. There is no let up in geophysics. Where, then, are the greener pastures? The greener pastures lie in new frontiers.

These new frontiers offer an equal or greater amount of promise. But where the old frontiers were geographical, the new ones are technical.

It takes an enterprising boldness and courage to explore where others have been before; you take a calculated risk that you can explore better. Why do members of the oil industry take these risks?

For one thing, we have a frontier for new ideas. There are alert minds constantly at work on technical improvements to instruments. I refer you to the

tremendous numbers of geophysical patents reported in GEOPHYSICS in the last fourteen years.

There are alert minds constantly at work on interpretational problems. Our early enthusiasm for the closed contour has turned to the imaginative exploitation of obscure or well hidden oil traps. One result of this is the "sweeping up," in our bag, of many small oil pools, and I refer you to the proposition that geophysically the big ones are far easier to find than the small ones.

I suspect that there are many technical minds at work on entirely new geophysical methods, and certainly the possibility of such developments enters into our consideration of frontiers.

Right now, a frontier of coordination of geology and geophysics is paying big dividends. No longer are these sciences separately pursuing the problem of discovery from different angles. Often inseparable, they now combine forces, dedicated to the fundamental idea that the putting together of all the data, both geological and geophysical, will tell you far more than any single method of attack.

I should like to define further these frontiers for you as they apply to our geophysical methods.

As far as virgin areas are concerned, these lands lie mostly outside the United States. When they become of interest, or become available, these lands are now quickly covered. For example, I refer you to the incredibly rapid coverage of the vast areas of western Canada initiated by the geophysical discovery at LeDuc in late 1946.

Let us consider the frontiers of the several geophysical methods available to us.

The frontier of magnetic surveys lies in interpretation. The airborne magnetic data now available provides magnetic pictures of such great accuracy and detail that tremendous strides in interpretation may be expected. By constant checking of magnetic data, both new and old, with new subsurface, seismic, and gravity data, we may expect to find important clues to structure manifested. One example might be a stratigraphic trap along the trend of a magnetic flexure.

The frontier for gravity surveys is very similar. Meters of great accuracy are today available, and interpretive techniques are progressing. Files packed with gravity surveys must be constantly reinterpreted along with development to be truly useful. An accurate survey already completed may be much more valuable in ten to twenty years. Another gravity frontier lies in density measurements at depth. The relationship of density of porosity is well known, and certainly one frontier of gravity methods lies in the accurate knowledge and interpretation of density contrasts.

The frontier of electrical methods, for surface work, still lies in the experimental development of exploration techniques. In electrical logging, the frontiers have already expanded rapidly, and a great new field for application of quantitative interpretations of electric logs is opening up. Here the geophysicist has made an outstanding contribution to the recognition of reserves once the wildcat well is drilled.

A vast frontier lies open and relatively unexplored for geochemical methods. It lies in the chemical analyses and correlation of oil shows, in the analyses of formation waters, and in the analyses and chemical correlation and mapping of geological formations. Rich rewards await the determination of the origin and source beds of oil, and earth chemistry may achieve this goal.

In spite of its universal employment, and of the widespread seismic coverage we have considered, the seismograph still offers the greatest frontier for geophysical methods. The first frontier lies in interpretation of seismic results. Here again our files are full of seismic records which probably have been interpreted by only one man and at the most, by two. These interpretations may have been made years ago. If they had been absolutely complete and correct interpretations, most all our oil would by now have been found, considering the seismic coverage picture. But it hasn't, and for that reason the seismogram should be constantly reworked along with subsurface development and the determination of regional velocity changes. Regional seismic maps should be made on all possible horizons. These regional maps should be supplemented with subsurface geologic maps in areas which have not been seismographed. Isopachus maps of zones significant for local areas should be kept up to date. No better method could be used for the discovery of stratigraphic traps.

Dr. Eckhardt last year stated, in his annual review of geophysical activity before this convention, that petroleum reserves discovered per year are proportional to the number of seismograph crew months. This is well shown by Figure 2. The point of no return will be reached in reflection methods, as it was in refraction methods, unless the methods used are constantly improved by ingenious application and greater accuracy.

For example, study of records in connection with velocity variation factors may lead to the discovery of isolated sand bars, to shoe string sands and to reefs. One contractor has been highly successful in finding shoe string sands in this manner in northern Oklahoma. Detailed studies of velocity variations may also lead to considerable structural variation on the interpreted map.

Continual care should be taken in field technique. Special seismic shooting methods should be tried in "NR" areas, which constitute local frontiers. Methods such as multiple geophones, multiple shots, air blasting, variation in shot hole depths, and spread variation and pattern may all be expected to contribute unexpected results. Use of these techniques may appear to raise the cost per seismic profile. However, nothing is more expensive than an "NR" profile.

Experienced interpreters should be ever present with the field party to help the observer obtain the proper results.

I believe the future seismograph recorder will be one capable of recording all seismic movements set off by the blast or other outside energy source. Seismograms so obtained may be "played back" through amplifiers of different types until the optimum record is obtained. At least one contractor is developing such a recorder and has given demonstrations.

One aspect of the seismic frontier is the universal application of continuous

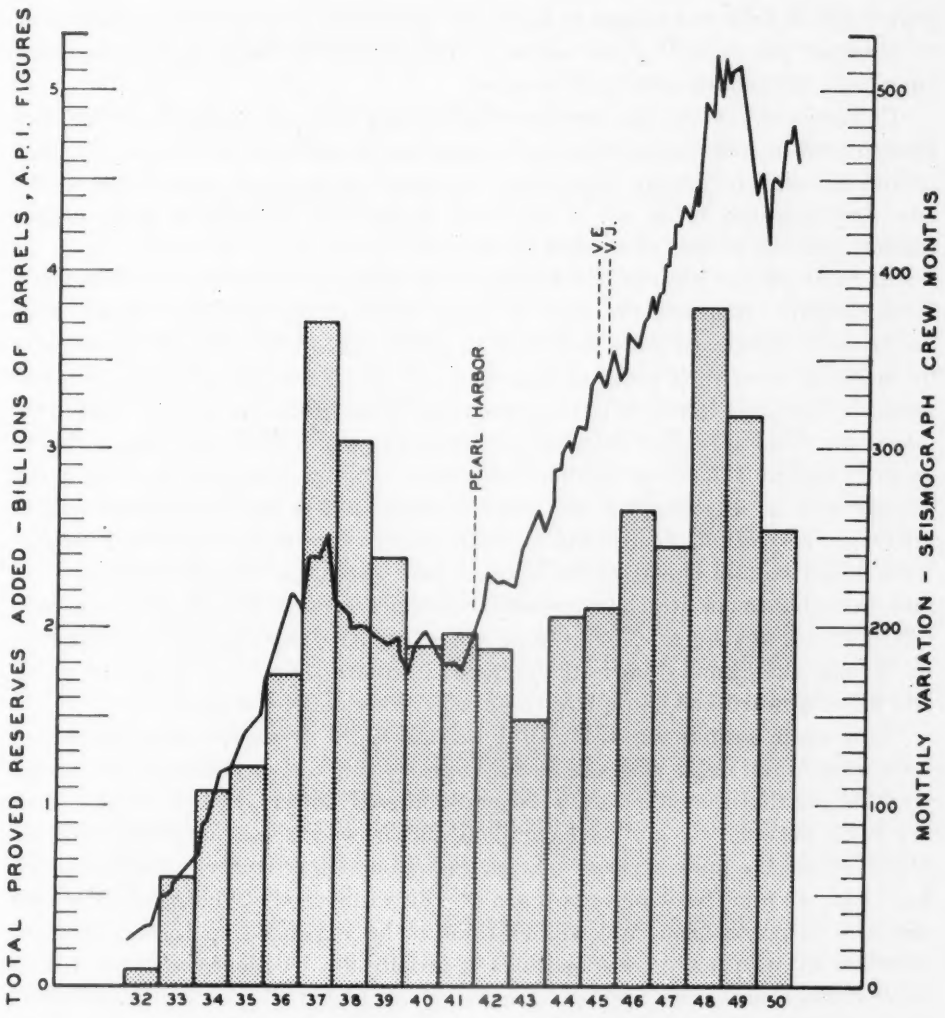

FIG. 2. Comparison of discoveries and seismograph activity in the United States.

profiling, replacing the older "spot" or correlation shooting. The use of continuous profiling will continue as greater detail is required, as will the use of closer spacing of geophone locations. The continuous profile method may be dangerous in the hands of inexperienced interpreters, and this is often indicated by maps whose contours change with the direction of the line of profiles.

The seismic frontier is advancing rapidly, and it is probable that many other advances in field interpretation and technique have been made by companies and contractors which at the present time are confidential. The seismograph field is highly competitive, and there have resulted many advances in equipment such as, for example, 24 or 36 trace records. The competition has also resulted in im-

provement of field techniques to speed up operations so that more profiles may be obtained per day. This, of course, is also dangerous, since many reflections have been left behind with speed in mind.

Collectively, a very vital frontier is laboratory and field research. Difficulties encountered in many areas when using geophysical methods, as well as the limitations encountered, make imperative continued research on geophysical methods. Any company using old or outdated geophysical methods is badly handicapped, and its chances of success are limited.

In most all the geophysical methods discussed, the number one frontier is interpretation. Who are the ones to make these interpretations? In no other endeavor is experience more essential. In geophysics these interpretations must be made by men with years of experience. You cannot develop a good interpreter by teaching him how to compute continuous profile records or remove regional dip from a gravity map. The interpreter should have a geological background, and he should be familiar with field conditions so that he may assist the operator in obtaining the best seismic results and in getting the best weathered layer correction. The interpreter must have a firm grasp of geology coupled with initiative and constructive imagination. This type interpreter is hard to find. Probably ten or fifteen trainees will be employed and trained before one good interpreter is developed. A continual stream of new talent should be employed to develop the "know how" interpreters to replace those who make the grade and move upward and to replace those who never make the grade.

This again sounds expensive, but what is more expensive than the wrong interpretation of data, which costs the industry millions of dollars in dry holes?

I believe that the oil industry recognizes these frontiers. In this country, during 1950, between six and seven million dollars were spent on geophysical research alone. We must suppose that at least a portion of this was spent in an effort to locate some basic new approach or a direct method of finding oil. The vast majority of it has been, and will continue to be, expended on these important frontiers within the old tried methods of geophysics. I believe, however, that if there exists a new basic approach, industry will find it. But as Ira Cram stated at the Ft. Worth regional meeting, "We can not afford to wait."

In conclusion, the record of the immediate past, including 1950, indicates that adequate future reserves will be discovered by present geophysical and geological methods. Across the frontier, as always, success will lie for the careful, for the exacting, and for the ingenious operator.

ACKNOWLEDGMENTS

The writer is indebted to Paul L. Lyons, Technical Assistant to the Chief Geologist, The Carter Oil Company, and R. R. Thompson, Head Geophysical Research, The Carter Oil Company for their able assistance in preparing this manuscript. Permission was granted by Dr. E. A. Eckhardt, Vice-President of Gulf Research & Development Company, for use of Figure 2 of the manuscript and by The Carter Oil Company for Figure 1.

GEOPHYSICAL ACTIVITY IN 1950*

E. A. ECKHARDT†

GEOPHYSICAL ACTIVITY IN THE OIL INDUSTRY

When we reviewed the geophysical activity of 1949 at our meeting last year, we looked back on a considerable decline in the United States from a high of 520 seismograph crew-months in November, 1948 to a low of 416 in February, 1950, the last month for which information was then available. We did not know at the time whether the decline would continue and, if so, how far. The atmosphere was one of concern. We noted, however, that economic and other factors strongly indicated an early reversal and the future surpassing of earlier peaks.

We did not know at the time that the February, 1950 level represented the bottom of the trough. The record for 1950 now makes clear that it was. Although the trend of 1950 was up, the total of seismograph crew-months in 1950 was less than it was in 1949, the decrease being approximately 6.9 per cent. This compares with a 1.4 per cent decrease from 1948 to 1949.

Gravity operations in the United States continued their 1949 decline somewhat longer, and the decrease was considerably more severe. The crew months in 1950 were over 45 per cent below those of the preceding year. During the latter part of last year a slight rising trend was in evidence.

The fluctuations of both seismograph and gravity operations from month to month over the past decade are shown in Figure 1. It is a pleasure to say that the reporting of gravity operations is again on an entirely satisfactory basis and that the estimating, reflected by the dotted portion of the gravity curve, was not necessary for last year.

The number of seismograph crews operating in the U. S. during November, 1950 is shown in Figure 1 to be 478. A recent publication based on statistics furnished by the Interstate Oil Compact Commission gives the corresponding number as of November 30, 1950 to be 415. A similar discrepancy was pointed out in the report to the Society of Exploration Geophysicists last year. As was the case then, the difference arises almost entirely from the fact that the Compact Commission data do not include crews which operated in North Texas.

Similarly the gravity graph of Figure 1 shows 62 parties to have operated in the U. S. during November, 1950. The corresponding number of the Compact Commission is 47. The difference arises primarily from the fact that gravity activity in the Rocky Mountain States was substantially greater than that shown by the Compact Commission records.

* Report of the Committee on Geophysical Activity of the Society of Exploration Geophysicists. The members of this committee are A. A. Brant, Herbert Hoover, Jr., D. C. Skeels and E. A. Eckhardt, Chairman. Presented at the St. Louis meeting of the Society, April 23, 1951.

† Gulf Research & Development Company, Pittsburgh, Pa.

The lower level of activity in the U. S. during last year represents one aspect of a trend away from the United States. This is evidenced by the fact that, more than offsetting the U. S. decrease, there was an over-all increase in seismograph activity on a world-wide basis. This increase was a modest one, amounting to 2.5 per cent, which is roughly half the rate of increase for the year before. There was the equivalent of 657 full-time seismograph crews in operation during 1950.

The global gravity effort was less in 1950 than it was in the preceding year,

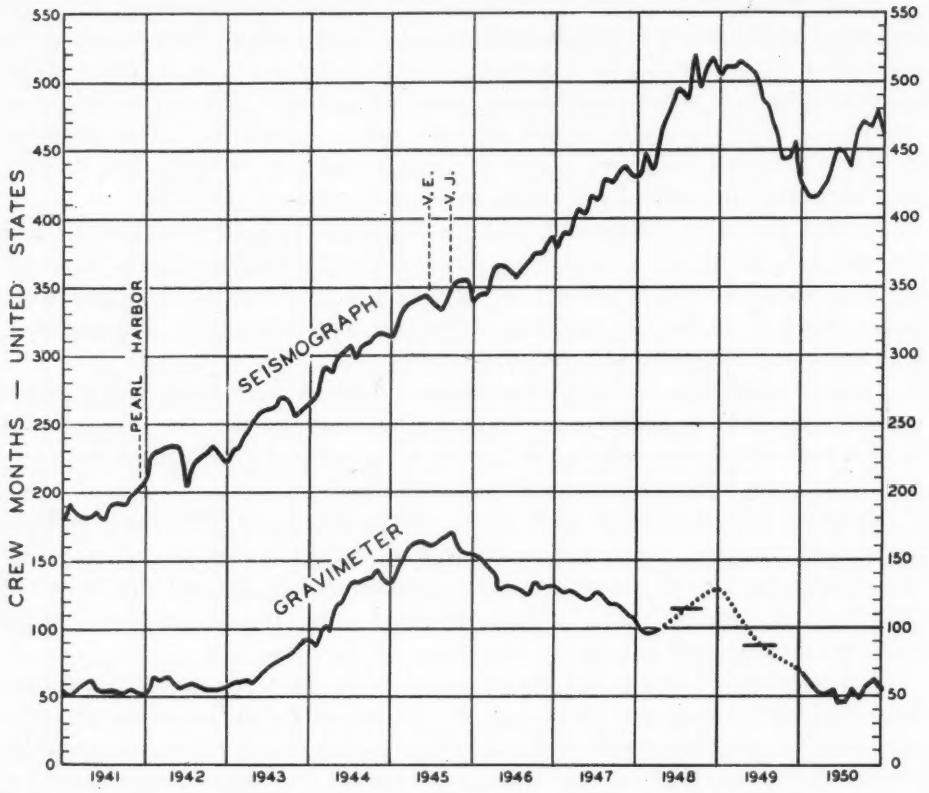

FIG. 1. Monthly variation in seismograph and gravimeter crew-months in the United States.

but the decrease was only 25.8 per cent and therefore substantially less marked than that which occurred in the U. S. The equivalent of 110 full-time gravity crews was reported as operating in 1950.

From the statistical evidence which has been presented, it is possible to make a reasonable estimate as to what the geophysical operations of 1950 have cost the oil industry. Including a guestimate of the amounts spent on geophysical research and development, one comes up with approximately $205,000,000. This figure is more likely to be too small than too large. It covers only the geophysical component of exploratory costs. It does not include land and lease costs, geological work, core drilling, or the cost of exploratory wells.

The world distribution of the seismograph work done in 1950 is shown in Figure 2. In this figure, as well as others shown in this report, the plus and minus signs associated with the percentages indicate increases or decreases with respect to the preceding year. The most striking feature of this world picture is the substantial increase of activity in Canada, which jumped from 9.54 per cent of the world total in 1949 to 15.13 per cent in 1950. Almost, but not quite, equal to the gain in Canada was the loss in the U. S., the percentage of which dropped from

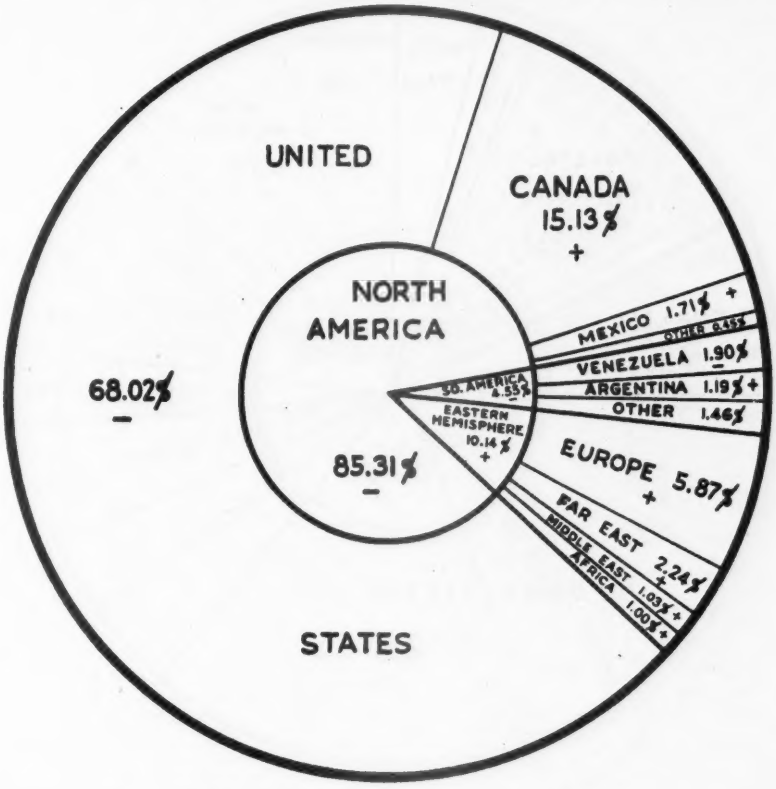

FIG. 2. World distribution of seismograph operations in 1950.

74.87 per cent to 68.01 per cent. Since the supply of trained geophysicists is quite limited and cannot readily be expanded, the increase in Canada was probably largely at the expense of activity in the U. S.

In South America the year 1950 witnessed a relatively severe shrinkage, and this continent's share of the total dropped from 6.29 per cent in 1949 to 4.55 per cent in 1950.

The reverse is true of the Eastern Hemisphere for which the percentage of the total increased from 7.53 per cent in 1949 to 10.14 per cent in 1950. The increase in Europe was most marked, especially that of Germany, but all divisions of the Eastern Hemisphere participated in the increase.

The distribution of 1950 seismograph operations in the United States is shown in Figure 3. The share of Texas dropped slightly, that of Louisiana, Mississippi and Oklahoma more markedly. The participation of the Rocky Mountain States increased substantially from 17.7 per cent of the total in 1949 to 23.1 per cent in 1951. Among the Rocky Mountain States, the share of Wyoming actually decreased from 7.7 per cent to 5.2 per cent, but New Mexico's share increased from 3.7 per cent to 7.0 per cent, almost doubling. All the other Rocky Mountain

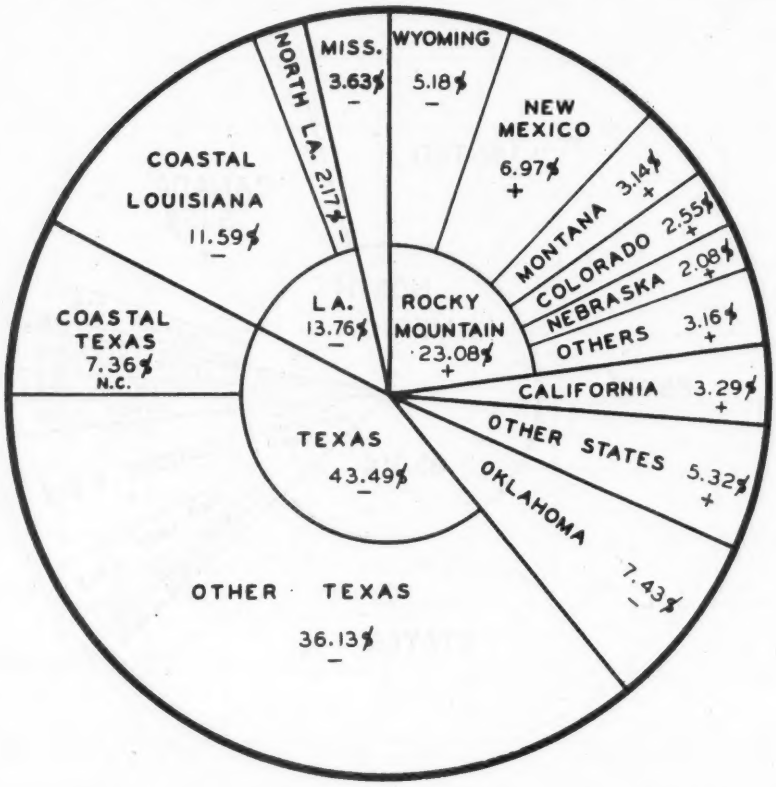

FIG. 3. Distribution of 1950 seismograph operations in the United States.

States showed relatively substantial increases. It is to be remembered that relative increases merely show better than average experience, since the sum total of all the work in the United States has decreased.

The magnitude and rate of growth of seismograph activity in Canada have been conspicuous in recent years. To gain perspective, however, it is useful to note that the 1950 activity in Canada was slightly less than that in the Rocky Mountain States and slightly over half of the activity in Texas.

The geographic distribution of gravity effort over both hemispheres is illustrated in Figure 4. In the preceding year the share of the United States was

over one half. In 1950 it fell somewhat below that proportion. The share of Canada decreased somewhat and that of Mexico rose. The combined effect of these changes was to reduce North America from 68.62 per cent in 1949 to 62.52 per cent.

There was an over-all decrease in South America, largely because of a reduction in Venezuela. On the other hand, the tempo of work in the Argentine and Brazil increased somewhat.

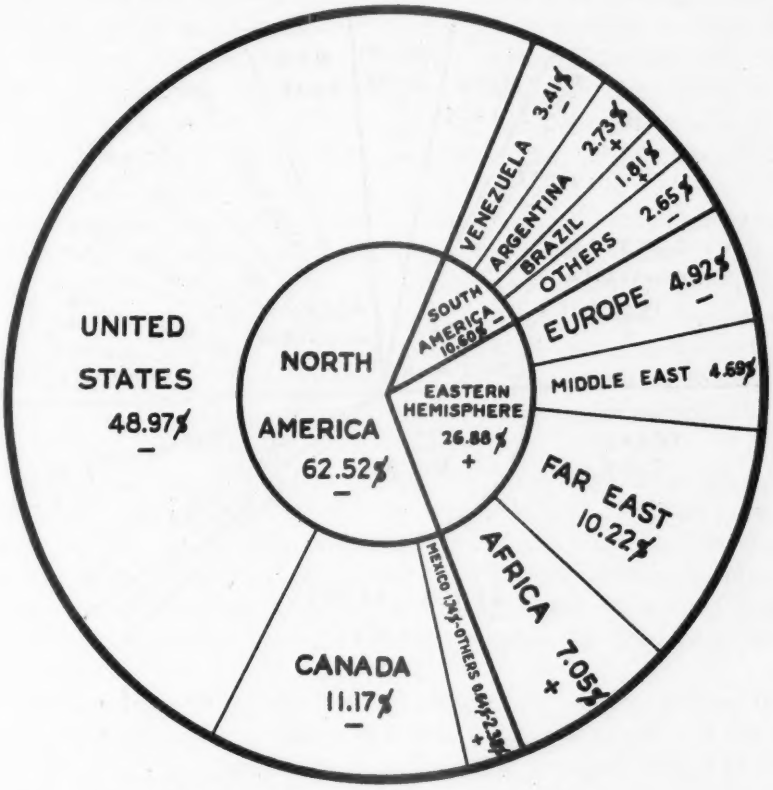

FIG. 4. World distribution of gravimeter operations in 1950.

The most striking change in gravity operations occurred in the Eastern Hemisphere, which increased from 19.78 per cent of the total in 1949 to 26.88 per cent in 1950. The most active area was the Far East. Africa was second, more than doubling its percentage of the total. Europe was the only major sector of the Eastern Hemisphere in which gravity operations declined somewhat.

The distribution of the 1950 gravity operations within the United States is shown in Figure 5. The State of Texas improved the commanding position held by it for some time by increasing its percentage from 34.81 per cent in the preceding year to 38.05 per cent in 1950. In Texas the trend was away from its

coastal areas. Louisiana also improved its position slightly, but here the trend was toward greater emphasis of the coastal areas. The greatest relative change occurred in North Dakota, which more than doubled its percentage of the whole. There was some increase in California. The sector for "other states" is much larger in 1950 than it was the year before, indicating that a small amount of work was done in each of a larger number of states which in the aggregate made an appreciable contribution to the total.

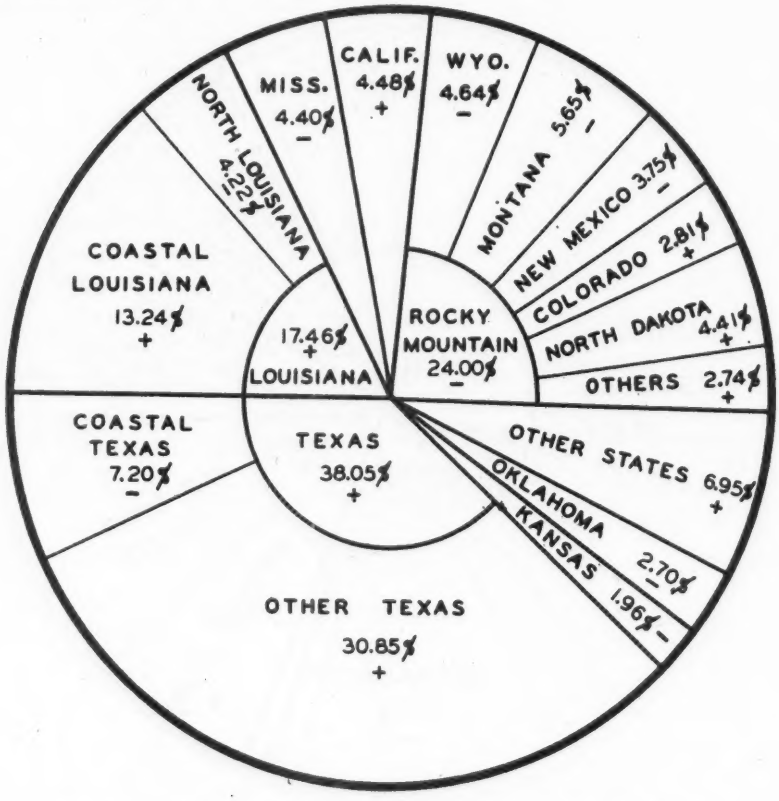

FIG. 5. Distribution of 1950 gravimeter operations in the United States.

A total of 259 ground magnetometer crew-months was reported for 1950. Of this number, nearly one half, 126, represents work done in North America. The Eastern Hemisphere accounted for 81 crew-months, more than two-thirds of this covering operations in the Middle East. South America accounted for 52 crew-months.

Statistics on airborne magnetometer work remain spotty. Operations in the United States decidedly exceeded those elsewhere, but activity was reported from Africa, Europe, Canada and Central and South America. While no measure of the magnitude of this work can be reported, it appears obvious that in terms

of area covered, the volume of airborne work is greater than that done on the ground by a considerable factor.

If these statistics provided only a record of what has happened in the past, few of us would be interested in them. What really counts is: "What do they portend for the future?"

Our biggest problem in the immediate future is likely to be man power. The effectiveness of geophysical exploration depends to a very large degree on sound technical training and on experience. The combined man-power pool of all geophysical operators is very limited, and there is a bleak prospect for any additions to it in the immediate future. It is more likely to shrink than expand. This will be no new experience since that is precisely what happened in the course of World War II. When we were in that position ten years ago, we tried to make the man power we had available stretch further by working them longer. We adopted extended work weeks and similar devices.

Geophysical field operations in normal times involve abnormally long working hours. Many operators have a normal 50-hour work week and most of them work regularly between 45 and 50 hours per five-day week. During World War II many, if not most, operators changed to a 60-hour, six-day week. Our experience with this was not satisfactory. The output per man was not increased proportionately, and there is reasonable doubt whether it was increased at all. In view of this experience, it is not reasonable to expect that capacity can be extended by working the personnel we now have for longer hours.

We will have other problems, of course, but the man-power problem towers above them all. If the geophysical activity the world over continues to increase, as it has in recent years, and American operators expect to retain the dominant position they have held for 25 years, this man-power problem must be solved. The maintenance of this position is not only of interest to the operators themselves. It is an asset of the entire economy which this country can ill afford to thoughtlessly surrender.

For the immediate future, the crystal ball seems to indicate a rising trend of geophysical operations in the United States as well as for the rest of the world. The demand is likely to exist and whether the potential expansion can be realized will depend largely on how well we succeed in conserving and expanding, if possible, our man power to the level required.

GEOPHYSICAL ACTIVITY IN THE MINING INDUSTRY

The expenditures by the mining industry for its geophysical work in 1950 appear to have been less than in the preceding year and amounted to between one and two per cent of the outlay of the oil industry for the same period and purpose. Mining geophysics employs a great variety of methods, and professional man-months appear to be better counting units than crew-months. For comparison purposes, however, money cost is the most useful common denominator, and it is the basis for the charts which are presented.

In proportion to its total expenditures the mining industry appears to have outspent the oil industry for research and development. Approximately 15.9 per cent of its outlays for geophysics were devoted to that purpose. In the preceding year, the figure was 17.95 per cent.

The geographic distribution of mining geophysical operations in 1950 is shown in Figure 6. The United States has succeeded Canada in the position of leadership by increasing its share from 23.8 per cent of the total in 1949 to 32.7 per

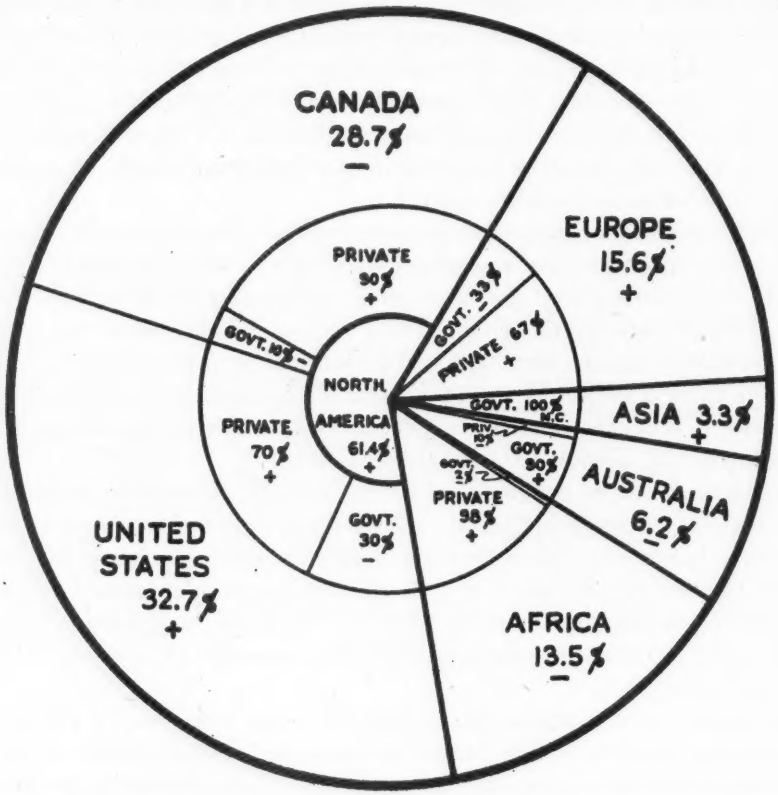

FIG. 6. World distribution of geophysical operations in mining, by areas, in 1950.

cent in 1950. Canada's corresponding change was a drop from 31.3 per cent to 28.7 per cent. Together, the U. S. and Canada accounted for 61.4 per cent of the total in 1950 as against 55.1 per cent in 1949. Operations in Europe increased from 8.9 per cent in 1949 to 15.6 per cent in 1950 and those in Asia, though still relatively small, doubled in relative magnitude. These gains were offset by substantial loss in the positions of Africa and Australia.

A greater portion of the 1950 mining geophysical work was done by or for the account of governments. In Africa, Canada, the U. S. and Europe, however, private interests paid a greater portion of the bill. Africa appears to be an out-

standing practitioner of private enterprise since private interest paid for 98 per cent of its geophysical operations. In Asia and Australia, the Governments footed virtually the entire bill, private interests accounting for 10 per cent in Australia, and none in Asia.

Marked changes have occurred in the distribution of effort between the methods, the situation in 1950 being depicted in Figure 7. In 1949 the largest slice of the pie went to magnetics, about 45 per cent of it. Electrical methods

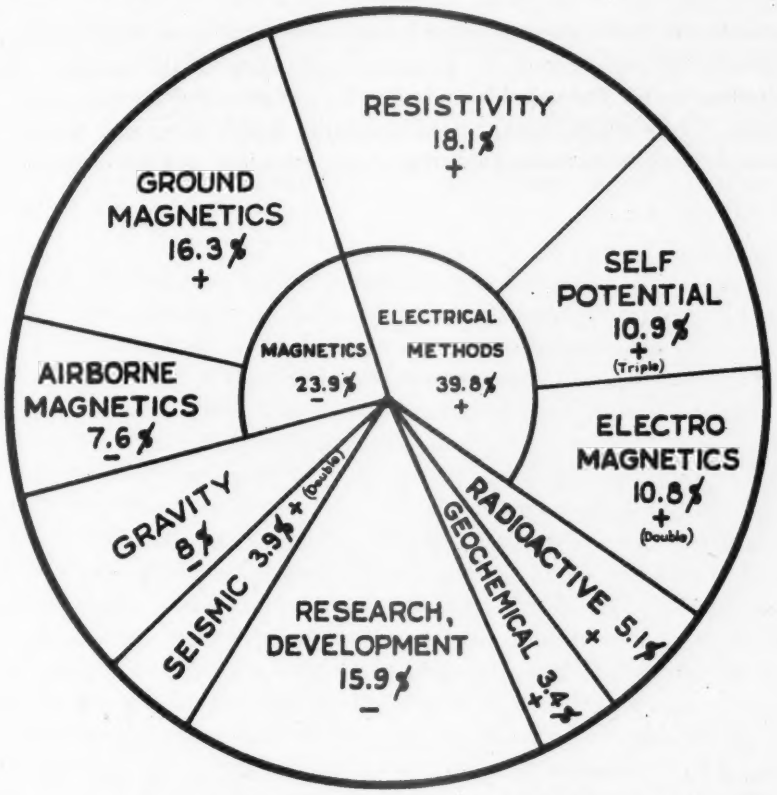

FIG. 7. World distribution of geophysical work in mining, by methods, in 1950.

were second with 22.1 per cent. In 1950, the picture is substantially reversed. Electrical methods represented 39.8 per cent and magnetics 23.9 per cent of the total. The most pronounced drop was in airborne magnetics which dropped from 31 per cent to 7.6 per cent. Ground magnetics, on the other hand, increased from 13.8 per cent to 16.3 per cent. There was increased use of all electrical methods in 1950, but the outstanding growth was in the use of the self-potential method which more than tripled its share and electro-magnetic methods which more than doubled, the percentage increasing from 4.9 per cent in 1949 to 10.8 per cent in 1950.

Otherwise, the 1950 operations were characterized by somewhat greater emphasis on geochemical, radioactive and seismic methods and decreased use of the gravity method.

The data for the activity in mining geophysics are estimated to be only about 60 per cent complete. This contrasts with a better than 98 per cent figure for the oil industry. The value of these statistics will be greatly enhanced by improving their completeness, and cooperation to that end of all concerned is invited.

The data on which this report is based have come from many sources, and any acknowledgment, here made, is small recompense for the interest and effort in assembling them. The capable and effective assistance of my colleagues on the committee in providing primary data in readily usable form and the aid of my associates at Gulf in compiling the report are gratefully acknowledged.

REGIONAL GEOLOGY AND GEOPHYSICS OF THE ARK-LA-TEX AREA*

CARL L. BRYAN†

ABSTRACT

The boundaries of the Ark-La-Tex area are arbitrarily defined and the exploration history of the area briefly reviewed. A Basal Upper Cretaceous structure map and two stratigraphic cross sections illustrate the regional tectonic movements contributing to the formation of the East Texas basin, the North Louisiana basin and the intervening Sabine Uplift. Exploration objectives and problems and the relation of magnetic and gravity anomalies and axes with regional geologic trends and structure are discussed. It is pointed out that the piercement dome type structure offers an almost untested field for further exploration. Illustrations include a vertical intensity magnetic map with contour interval of 100 gammas, a Bouguer gravity map with contour interval of 5 milligals and type seismograph records.

The Ark-La-Tex area, for the purpose of this discussion, is arbitrarily defined as that area lying between the Luling-Mexia fault zone of northeast Texas on the west and the Monroe Uplift of north Louisiana on the east. The northern boundary is the south flank of the highly folded Ouachita Mountains and to the south lies the Gulf Coastal Plain. The area extends some 200 miles from east to west and about 180 miles from north to south.

In this area of approximately 36,000 square miles, the first oil well, the Savage Brothers and Morricell No. 1, was completed on March 28, 1905 as a 5-barrel per day producer from the Annona chalk. This was the discovery oil well of the Caddo Field in Caddo Parish, Louisiana. From that date to January 1, 1950, this tri-state area has produced more than $4\frac{1}{2}$ billion barrels of oil and condensate and large quantities of gas. Arkansas and Louisiana each has produced about $\frac{3}{4}$ billion barrels of oil and condensate, and Texas, with its $2\frac{1}{2}$ billion barrel East Texas field, has produced a little over 3 billion barrels.

Exploration continues active over the entire area as evidenced by the fact that during 1949, 70 exploratory wells were drilled in southwest Arkansas resulting in the discovery of 11 new fields and new pools or extensions of old fields. In northwest Louisiana, 139 exploratory wells resulted in 21 discoveries of new fields and new pools or extensions of old fields. In East Texas, the drilling of 121 exploratory wells led to the discovery of 11 new fields and 5 new pools or extensions of old fields.

In geophysical exploration, an average of 1 magnetic, 2 gravity and 7 seismograph crews operated in southwest Arkansas during 1949. During the same period, northwest Louisiana averaged 6 gravity and 16 seismograph crews. East Texas averaged 3 gravity and 8 seismograph crews. Magnetic surveys are re-

* Delivered at the Joint Regional Exploration Meeting, Fort Worth, Texas, December 1, 1950. Manuscript received by the editor December 29, 1950.

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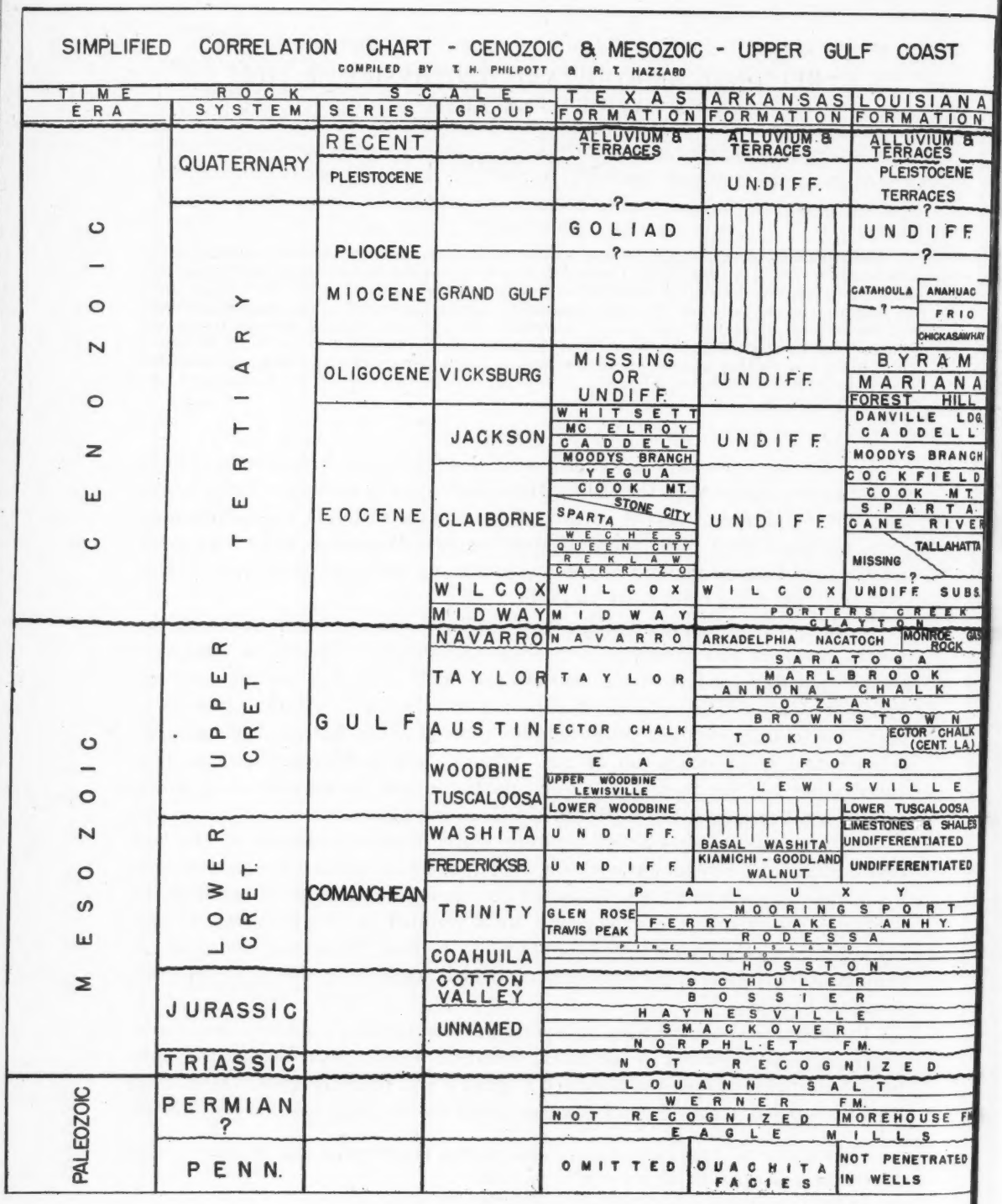

FIG. 1. Simplified correlation chart.

ported to have been made in Louisiana and Texas during 1949 but no figures are available from which to estimate the extent of such work.

A much simplified correlation chart is presented in Figure 1 after the chart published in the guide book of the 17th Annual Field Trip of the Shreveport Geological Society in 1949. The chart shows only the general stratigraphic relationships to be referred to in this discussion; therefore some formations and members have not been designated, as for instance, in the Washita and Fredericksburg groups where the formations have not been differentiated.

Of considerable importance, and sometimes annoyance, in the interpretation of both subsurface and seismograph data are the unconformities common to the area. The most important, perhaps, and the best known from well control, is the unconformity at the base of the Upper Cretaceous. In Louisiana and Arkansas this unconformity becomes of profound magnitude where to the northeast of Caddo Parish, Upper Cretaceous beds may be found resting on successively older beds of the Lower Cretaceous, the Jurassic, the Permian, and in the extreme northeast corner of the area, on the Ouachita facies of the Paleozoic rocks of probable Mississippian or Pennsylvanian age. Other unconformities are shown on the chart and are of greater or less importance as they may contribute to the formation of stratigraphic traps or may become nonconformities where structure is present. For example, in the Haynesville and East Haynesville fields in northern Claiborne Parish, Louisiana, a nonconformable relationship of perhaps 3 degrees of angularity has been found to be present between the beds of the Cotton Valley group and the older Jurassic beds. With a number of major unconformities in the section, it is apparent that, in seismograph interpretation, reasonably accurate vertical velocity data are essential.

A regional structure map on the base of the Upper Cretaceous datum is shown in Figure 2. At the risk of oversimplification, it may be said that the regional structure of the Ark-La-Tex area is characterized by two basins, the East Texas Basin and the North Louisiana Basin, separated by the broad positive area generally referred to as the Sabine Uplift. The north flank of the Sabine Uplift, to the depths known from drilling, lies just north of the Arkansas-Louisiana state line. The dips along the south flank flatten southward so that they are about the same as the general Gulf Coastal dip at the south edge of the map.

The structural map here presented shows the tectonic development of the area since the beginning of Upper Cretaceous time. Subsidence of the basins and rise of the Sabine Uplift continued at least well into Eocene time since the Wilcox formation shows coincident structure and crops out at the surface over the central part of the Sabine Uplift while younger formations of the Claiborne group are found on the surface over the deeper parts of the basins.

It is interesting to note that the shallow piercement domes, shown by solid circles, are grouped rather closely about the axes of the basins. In southwest Arkansas where beds of Jurassic age and younger dip gently south to southwest, the Louann salt, thought to be Permian in age, has been encountered in a score

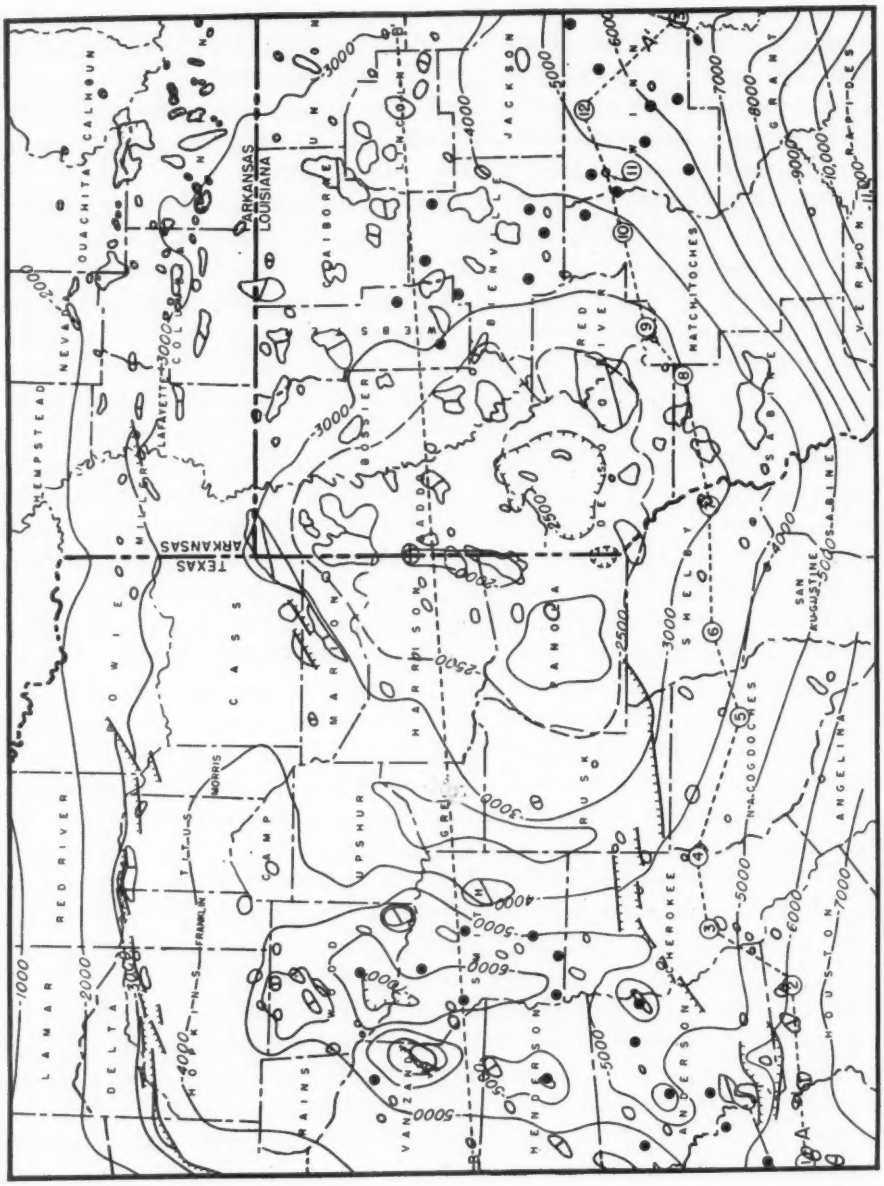

FIG. 2. Subsurface structure map. Datum—Base Upper Cretaceous.

or more of wells, the maximum thickness reported being 1,300 feet in a well in Calhoun County. In this area where the depth to the top of the salt probably never exceeds 12,000 feet and where the shallowest known depth is about 5,500 feet, no piercement domes have been found. Similarly, no piercement dome is known to have developed within the structurally high part of the Sabine Uplift, although a well drilled in northern Caddo Parish very near the north-south axis of the uplift penetrated 1,176 feet of Louann salt. This absence of piercement domes on the uplift is therefore not due to absence of salt.

Two factors are believed to be of major importance in controlling the movement of salt into groups of piercement domes in the deeper parts of the basins. The first factor is that of thickness of the mother salt bed wherein the salt must attain some critical thickness, less than which salt does not form domes of the piercement type. This theory was discussed by Parker and McDowell[1] in a paper delivered at the 1950 Annual Meeting of the American Association of Petroleum Geologists. It follows from this hypothesis that in the Ark-La-Tex area, more salt was deposited in the basins than on the Sabine Uplift; in other words, the basins were present at the time of salt deposition. The second factor is that of critical loading. It is possible that salt does not begin to move until depth of burial is considerable. In other words, the basins were enough deeper than the uplift after deposition of the salt to start movement into piercement domes, and as the basins were later becoming the site of more sediments than the uplift, movement of the salt was later given additional impetus. Although these theories represent the views of many students of salt dome phenomena, there is some evidence that the salt did not move substantially until Eocene time; also, that the basins were not of great relief until the same time. To resolve the conflicting theories, we shall require more geophysical and also more well data adjacent to the piercement domes, and these data as of today quite meager.

Although oil and gas fields are present both on the uplift and in the two basins, only in one—the Boggy Creek field in Anderson and Cherokee Counties, Texas—is there commercial production which may be related to movement of flank beds on a shallow piercement salt dome. Why was not commercial production found in others of the 17 domes in the Louisiana basin and the 16 in the East Texas basin? In the first place, the drilling to date is quite meager and it may be that the lack of more oil is simply due to the pitiful deficiency in observational data. In many cases our knowledge is limited to the top of the salt plug. In the north Louisiana basin, for example, two of the 17 domes are known only from surface geology. Eight domes have had no exploration tests drilled on the flanks of the salt plugs. Although numerous shows of oil and gas have been reported in the shallow wells drilled, the deepest test on any of these domes reached a total depth of only 6,432 feet (Packton Dome, Winn Parish) and this test may be located on top of the salt plug. It is therefore possible that inadequate explora-

[1] Travis J. Parker and A. N. McDowell, *Progress Report—Salt-Dome Phase, Experimental Tectonics* (*A.A.P.G. Project 11*). Delivered at Annual A.A.P.G. Meeting in Chicago, April 24, 1950.

tion is the only reason for the absence to date of oil or gas production in commercial quantities from the piercement dome structures. This is a challenge to the exploration geologist and geophysicist to devise means of delineating such complicated structures.

An alternate explanation of the absence of commercial production may be that the history of these salt domes was unfavorable to preservation of any oil or gas which was being formed. It is conceivable that movement of the salt plug upward has been continuous or intermittent, but at such rate that its top has been lifting only the relatively unconsolidated sediments near the surface at any one time, and the faulting caused by such uplift provided an avenue of escape for such hydrocarbons as were being collected into these sediments. On the other hand, if we accept the hypothesis that the salt domes formed very late, say in Eocene time, we might attribute the absence of oil on so many of them to its migration elsewhere before salt movement formed structures or traps.

Piercement domes definitely have not been explored in this region, either geophysically or with the drill, as thoroughly as those in the Gulf Coast. For example, no radial refraction from a central well into the salt plug has been tried, as has been done in many of the coastal domes. In 1910, Harris[2] wrote, "The saline domes of northern Louisiana have yielded so far little oil or gas. But they have been very slightly exploited, especially in the light of present knowledge regarding their structure." That statement could be repeated today, forty years later, without qualification.

The locations of oil and gas fields by irregular outlines in Figure 2 show the general distribution of production in the Ark-La-Tex area. The domal or anticlinal structure, with or without associated faulting, is the predominant type of oil trap in the area but other types are also represented. The Cotton Valley field in northern Webster Parish, Louisiana, is a representative example of the simple domal structure undisturbed by significant faulting. In Arkansas, particularly in Columbia and Lafayette Counties, the typical structure is anticlinal with roughly east-west elongation. Spencer and Peters,[3] in their case history of the Magnolia field in Columbia County, conclude from seismograph and gravity data that the elongated anticlinal structure is due to salt thickening and uplift of the overlying sediments.

The Talco field in northern Titus and Franklin Counties, Texas, the Fouke field in central Miller County, Arkansas, and the Rodessa field at the common corner of the three states are examples of the trap relying on closure against a fault plane. In these cases, the productive reservoirs are found on the upthrown sides of the faults.

Of stratigraphic traps associated with an unconformity, perhaps the world's leading example is the East Texas field where the productive sands pinch out on

[2] G. D. Harris, "Oil and Gas in Louisiana," *U.S.G.S. Bulletin 429*, p. 11.

[3] L. C. Spencer, Jack W. Peters, "Magnolia Field, Columbia County, Arkansas," *Geophysical Case Histories, Vol. 1* (1948), 443–460.

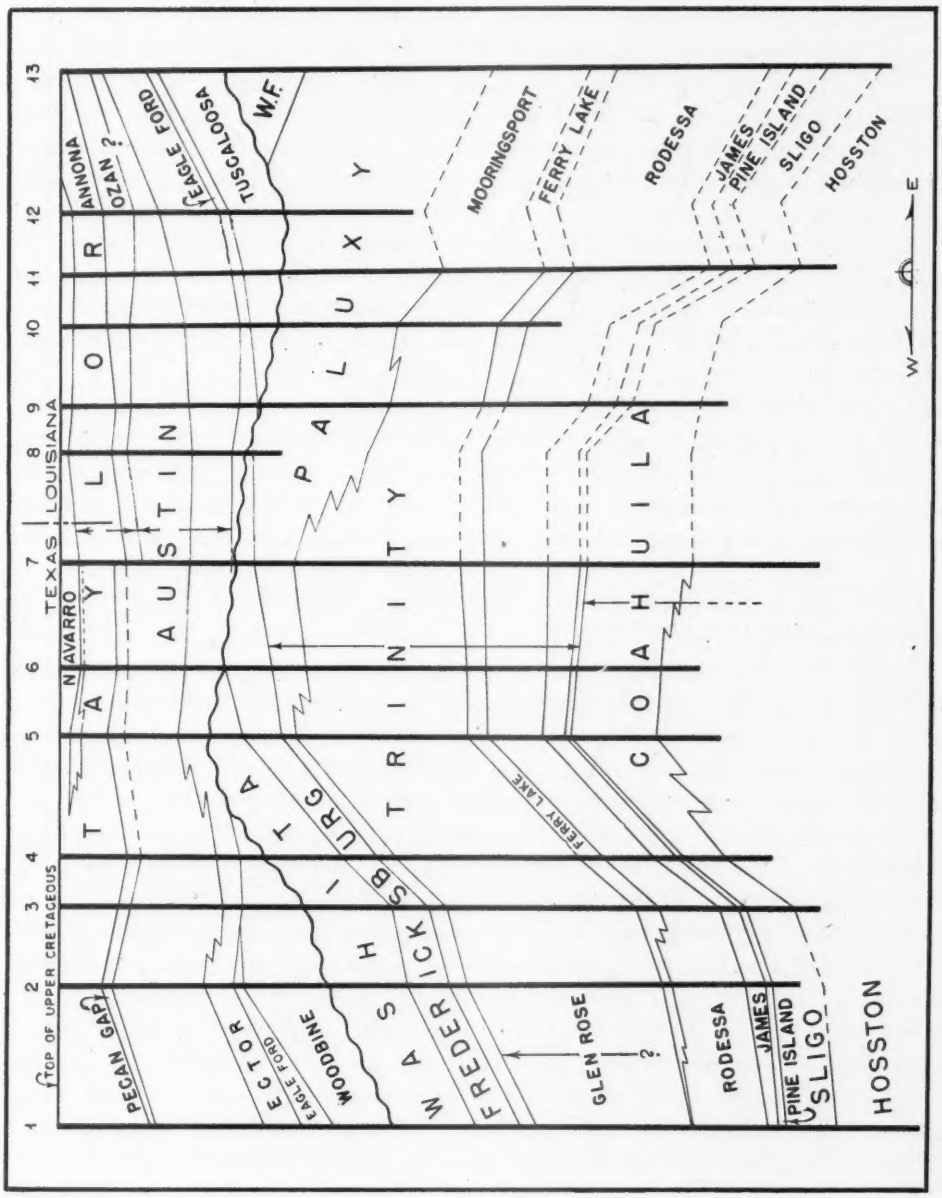

FIG. 3. Stratigraphic cross section AA'.

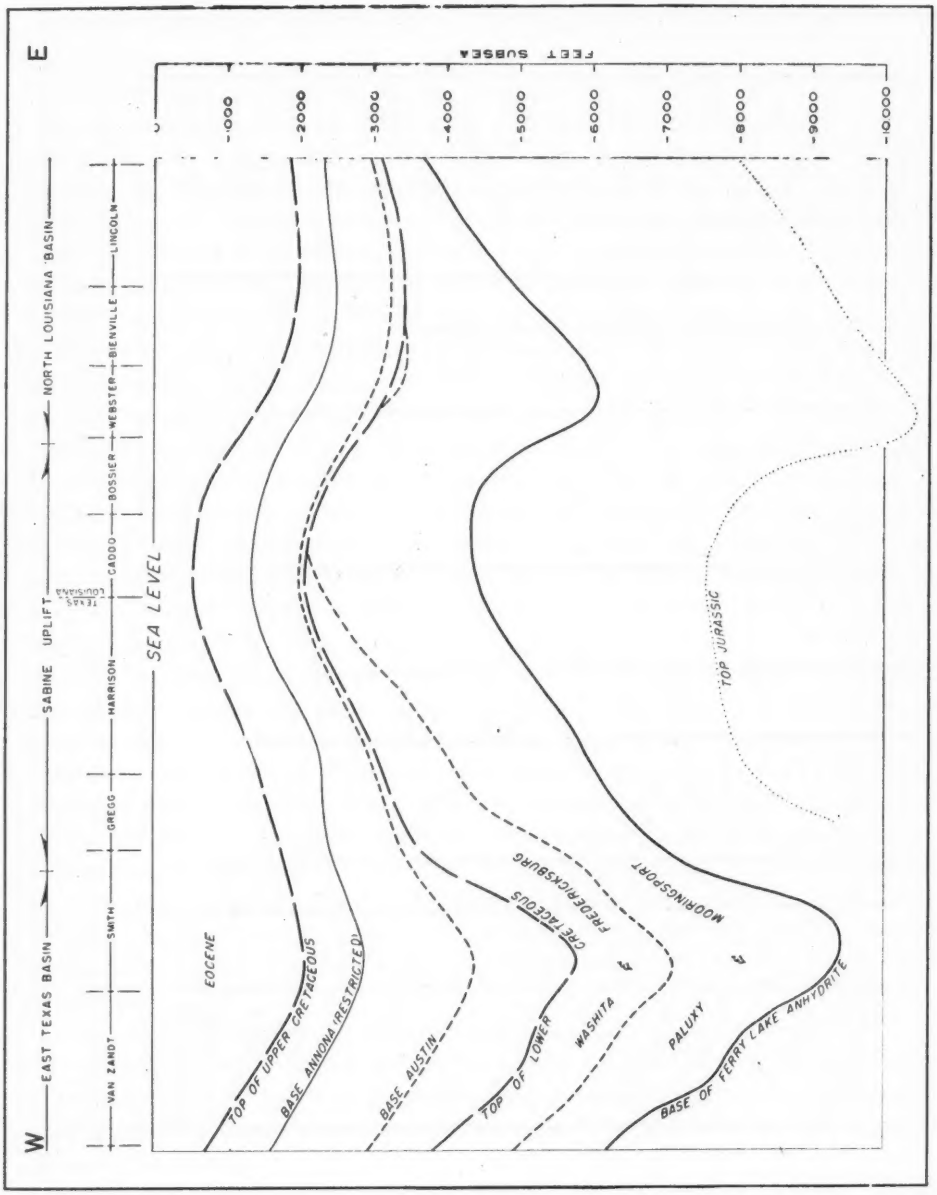

FIG. 4. Idealized cross section BB'.

the west flank of the Sabine Uplift. Lenticularity of sands, usually associated with structure, plays a prominent role in oil accumulation in many fields. It may even be possible that the Ark-La-Tex area can boast of reef production. In the Haynesville and East Haynesville fields in northern Claiborne Parish, Louisiana, an oolitic limestone facies of possible Haynesville age, but more commonly referred to as the "A" Zone of the Smackover formation, is considered by some to have "reef-like" characteristics. Due to the sparsity of subsurface information, this question is still highly controversial and much more evidence is needed to establish a consensus.

In the southern part of the map in Figure 2 the location of the stratigraphic section of Figure 3 is shown by a line of individual wells, approximate locations of which are indicated by numbered circles. This stratigraphic cross section extends from Leon County, Texas, on the west end to Winn Parish, Louisiana, on the east. The data are referred to the top of the Upper Cretaceous datum. Note the unconformity between the Upper Cretaceous and Lower Cretaceous as mapped in Figure 2. The Washita and Fredericksburg groups are missing over a part of the Sabine Uplift where the Tuscaloosa beds of Upper Cretaceous age rest unconformably on Paluxy beds of the Trinity group. This cross section shows the stratigraphic relationship of Upper Cretaceous and Lower Cretaceous beds at the close of Upper Cretaceous time.

In Figure 2, the line BB′, extending from Van Zandt County, Texas to Lincoln Parish, Louisiana, represents the location of the cross section shown in Figure 4. From an assortment of contoured data and some individual well control, this idealized section has been compiled to give a view of the magnitude of the regional movement involved in the development of the Sabine Uplift and the flanking basins. The section was located so that it crosses the Sabine Uplift near its highest point and the basins near the points of greatest depths as known from present control. The section was also located to avoid local structures as much as possible. Any effect from local structure has been smoothed to avoid complication of the regional relationships. This cross section reveals that a much thicker section of sediments has been preserved in the East Texas basin during late Lower Cretaceous and early Upper Cretaceous time than in the Louisiana basin. In late Upper Cretaceous time, the rate of deposition appears to have been more nearly uniform and essentially the same in the basins as on the uplift. This suggests that along the line of this section, a temporary period of relative stability may have been experienced during late Cretaceous time. It is noteworthy that the Nacatoch sands of this interval were relatively uniformly deposited and constitute an important reservoir bed over a large part of the Arkansas and Louisiana areas.

Figure 5 presents a map of the vertical magnetic intensity with a contour interval of 100 gammas. The contouring is based on a control density varying from a few stations per township to a few stations per county or parish. This map covers the same area shown on the subsurface map of Figure 2 and the piercement

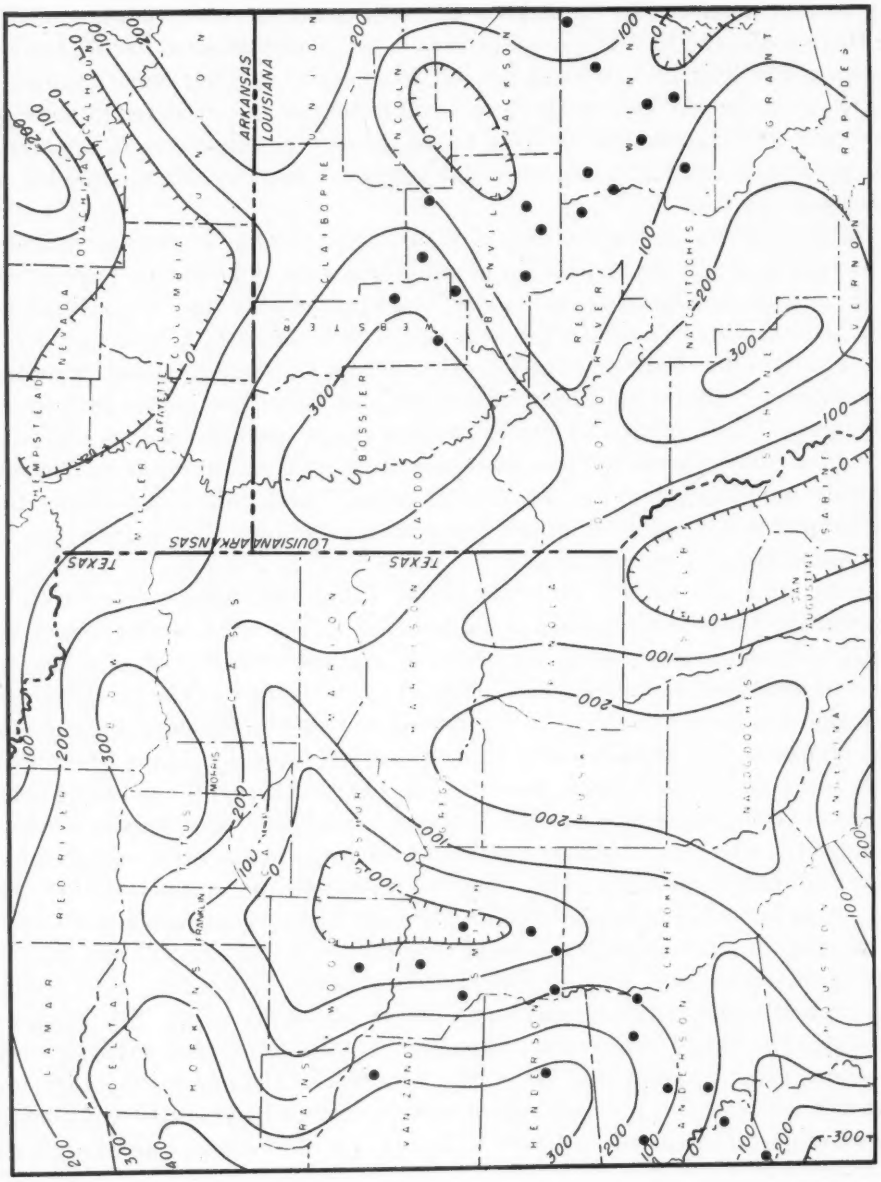

FIG. 5. Vertical intensity magnetic map. Contour interval—100 gammas.

salt dome locations repeated here serve to designate roughly the Texas and Louisiana basins. If we consider the central area incorporating the Bossier Parish, Sabine Parish, and Rusk County maxima, we may get the impression that these maxima, taken together, assume something of the shape and areal extent of the Sabine Uplift. In the western part of the map, it may also be noted that the axis of the magnetic minimum through Smith County is generally coincident with the axis of the structural basin. Similarly, a magnetic minimal axis coincides with the axis of the Louisiana basin. Thus, knowing something of the regional structure of the area, it is possible to pick confirming trends and axes. If, however, such a map were available in an area about which nothing else was known, it is extremely unlikely that the structural conditions of the Ark-La-Tex area would be predicted. Anomalies shown here are of such magnitude and areal extent that they are much more likely, as Peters[4] points out, to be related to lateral variations in the magnetic properties of the igneous basement. Such may in fact be the case here. However, with adequate density of observations and the resultant refinement of magnetic trends and depth estimates, such regional anomalies and possible local anomalies should arouse interest in continued exploration by other available means. An indirect measurement of the usefulness of the magnetic method of exploration may be deduced from the fact that magnetic surveying has been in progress in the Ark-La-Tex area to a greater or less extent for the past quarter century.

Several sources have made it possible to present in Figure 6 a regional Bouguer gravity map of the Ark-La-Tex area with a contour interval of 5 milligals. Local anomalies, except those of salt domes of great gravity relief, are not apparent. Trends and axes do conform to some extent with the regional structure. The axis of the East Texas basin is parallel with and offset slightly to the west of a minimal gravity axis which swings east in the northern part of the area and crosses the productive area of southwest Arkansas in a nearly east-west direction. It may be of significance that many of the oil producing structures of Arkansas are elongated east-west.

The North Louisiana basin appears closely associated with a maximal gravity axis. It may at first glance seem paradoxical that here we have a salt basin associated with a gravity maximum while we have just mentioned that the East Texas basin is associated with a gravity minimum. The assumption of a reasonable salt thickness and density contrast would account for a gravity anomaly of 5 milligals or one contour interval on this map. If that effect were subtracted from the North Louisiana basin anomaly, the result would be only the addition of one contour to the gravity maximum. The gravity picture would not be appreciably altered thereby, nor would it justify the conclusion that no salt was present in the basin. This comparison simply confirms Nettleton's[5] observation

[4] Leo J. Peters, "Magnetic Interpretation and Its Practical Application," *Geophysics, Vol. XIV, No. 3* (July 1949), 290–320.

[5] L. L. Nettleton, "Geophysics, Geology and Oil Finding," *Geophysics, Vol. XIV, No. 3* (July 1949), 273–289.

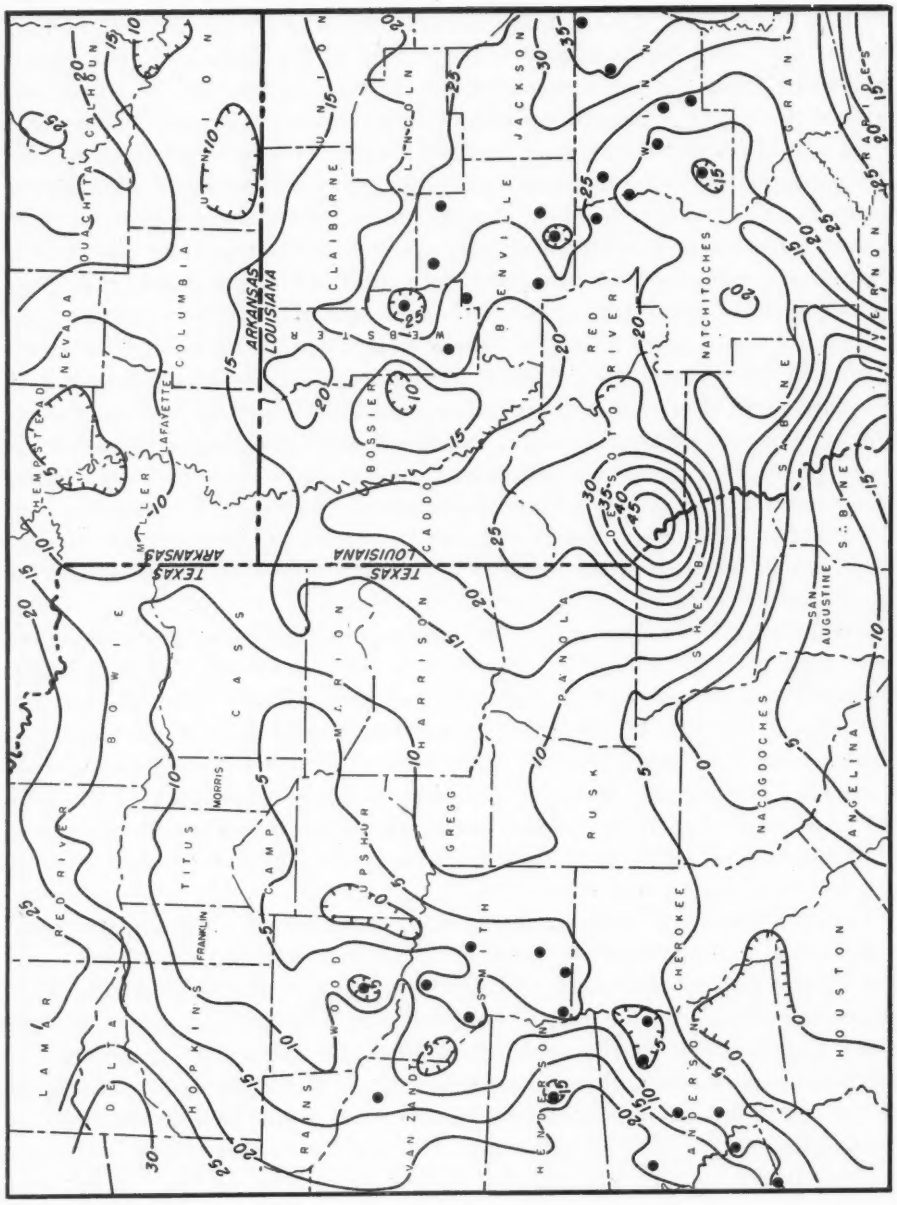

FIG. 6. Bouguer gravity map. Contour interval—5 milligals.

that in view of the possibility that the mother salt bed thins as the edge is approached, using reasonable assumptions of salt thickness and density contrast, there is little probability that a salt basin could produce an anomaly apparent to the eye.

One other pronounced gravity axis appears on the gravity map. Near the Louisiana-Texas state line, a north-south maximal axis is closely coincident with the structural axis of the Sabine Uplift. Assuming that regional gravity variations shown here arise from density contrasts at great depths, this coincidence would support the theory of origin of the Sabine Uplift as a basement movement. The relationships between gravity and magnetic axes and structural disturbance suggest that, in addition to the well-known usefulness of the local anomalies observed by potential field exploration methods, a consideration of trends and axes may be of value in analyzing the broader regional geology of an area.

From the standpoint of crew-years as well as money invested in geophysical exploration, the reflection seismograph has been and continues to be the most useful method of geophysical exploration. Geological and surface conditions throughout the entire Ark-La-Tex area are favorable for this type of instrument. It is sometimes difficult to obtain reflections from a specific geologic section, but in general, it is possible to map reflecting horizons in the Eocene, the Upper Cretaceous and the Lower Cretaceous. In addition, in areas where the Jurassic sediments are prospective producing horizons within reach of common drilling depths, one or more reflecting horizons can usually be mapped in this section.

In Figure 7, the upper reflection seismograph record is from Columbia County, Arkansas, and is typical of that area where it is customary to map an Upper Cretaceous, a Lower Cretaceous, one or more Jurassic and sometimes the Louann salt reflecting horizons. As this record indicates, the Ferry Lake anhydrite, where present, is one of the better reflectors in the Lower Cretaceous. The top of the Smackover limestone, although a good lithologic marker, is generally a poor reflecting horizon. Over a limited area in the southern counties of Arkansas, the top of the Louann salt and possibly the base give usable energy return, but subsurface control not now available will be required before unique solutions can be made of its many interpretation problems.

The type Louisiana reflection record shows reflection energy from about the same geologic horizons as noted on the Arkansas record, but here these horizons lie at progressively greater depths. The record probably ran long enough to have recorded any reflected energy from the top of the Smackover, but if so, here is confirmation of the poor reflection response of that geologic horizon.

The type Texas record shows numerous bands of reflected energy throughout the Mesozoic section. Drilling in the area has not been deep enough to give subsurface control from which the reflected energy between 2.2 and 2.4 seconds can be identified, and it is not known if these deeper events can be mapped over any substantial area. The writer concurs with Weaver[6] in that, in a general way,

[6] Paul Weaver, Gulf Oil Corporation, personal communication.

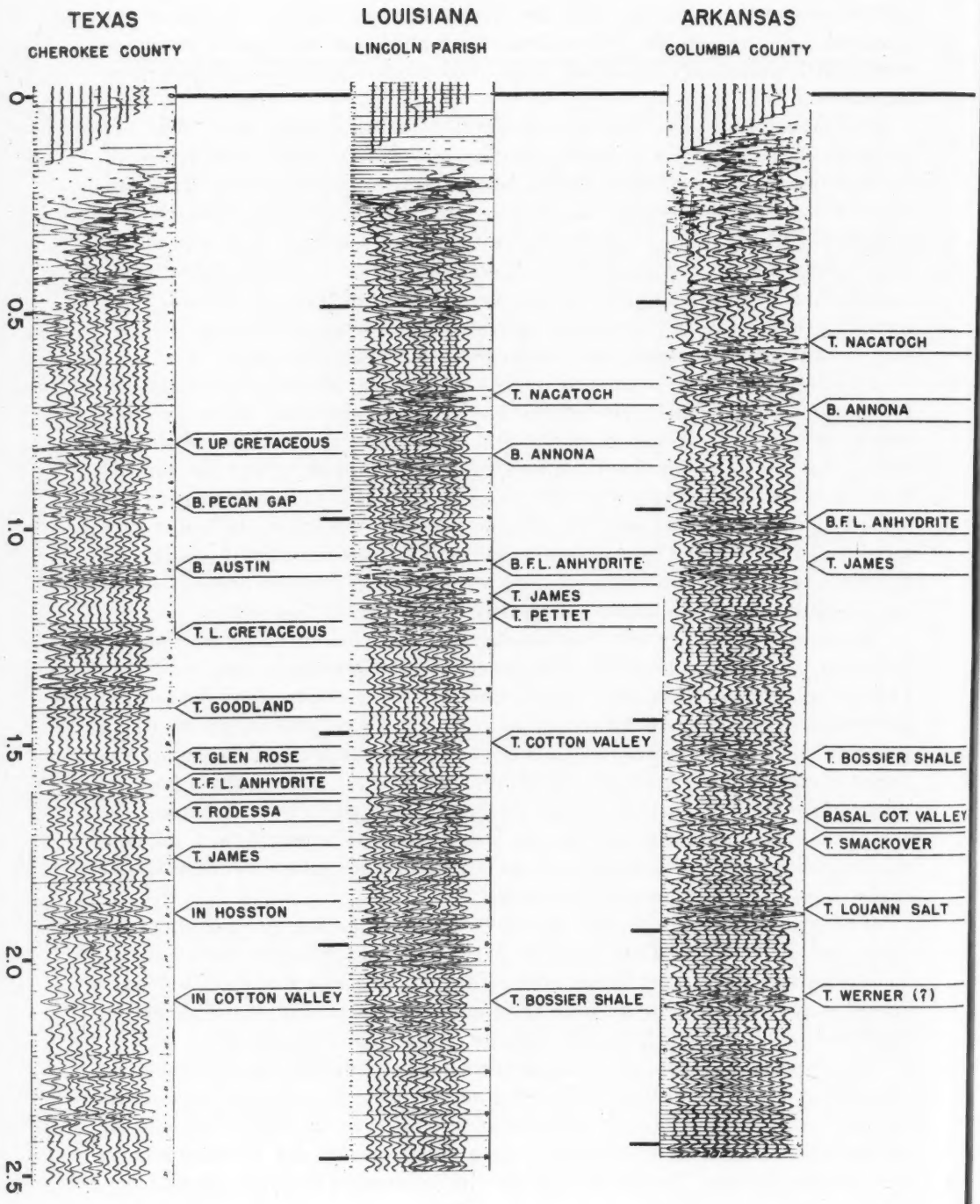
TEXAS
CHEROKEE COUNTY
LOUISIANA
LINCOLN PARISH
ARKANSAS
COLUMBIA COUNTY
0
0.5
1.0
1.5
2.0
2.5
T. UP. CRETACEOUS
B. PECAN GAP
B. AUSTIN
T. L. CRETACEOUS
T. GOODLAND
T. GLEN ROSE
T. F. L. ANHYDRITE
T. RODESSA
T. JAMES
IN HOSSTON
IN COTTON VALLEY
T. NACATOCH
B. ANNONA
B. F. L. ANHYDRITE
T. JAMES
T. PETTET
T. COTTON VALLEY
T. BOSSIER SHALE
T. NACATOCH
B. ANNONA
B. F. L. ANHYDRITE
T. JAMES
T. BOSSIER SHALE
BASAL COT. VALLEY
T. SMACKOVER
T. LOUANN SALT
T. WERNER (?)

FIG. 7

seismograph interpreters do not try to go very much below the driller in any particular area, and in turn, the clients of reflection seismograph crews seldom ask for contour maps at depths greater than known producing zones in the area are believed to lie or where some objective is already known as to depth. This is an unfortunate situation because in reviewing records shot, say, fifteen years ago, workable reflections are sometimes found thousands of feet below those originally mapped. This suggests that a currently active academic curiosity on the part of both client and interpreter might prove economically fruitful in the future.

CONCLUSION

The Ark-La-Tex area, although one of the oldest oil producing provinces in the United States, is still an area of active exploration by both geophysical methods and the drill, with such exploration continually resulting in discoveries of new oil and gas reserves. The piercement domes of the two basins demand a vigorous attack by new exploration methods or a refinement of the old techniques in order to discover any oil which may be trapped in the complicated structures associated with such salt movement. Magnetic, gravity and seismic methods continue to be effective exploration tools throughout the Ark-La-Tex area.

ACKNOWLEDGMENTS

The writer wishes to thank the many members of the Ark-La-Tex Geophysical Society of Shreveport whose cooperation and effort made this compilation possible. In both illustrations and text, published data have been liberally used in combination with new data gratefully received from contributors too numerous to list individually. The writer is especially indebted to Roy T. Hazzard, T. H. Philpott and Paul Weaver for valuable advice and criticism and to James A. Sullins and Mildred G. Kendrick for drafting the illustrations. Permission for publication, granted by the management of Gulf Refining Company, is gratefully acknowledged.

GROUND ROLL COUPLING TO ATMOSPHERIC COMPRESSIONAL WAVES*

FRANK PRESS†‡ AND MAURICE EWING†

ABSTRACT

A theoretical treatment of ground roll originating from air shots and hole shots is given. It is shown that coupling of ground roll to compressional waves in the atmosphere exists for both air shots and hole shots. Experimental data obtained in the field are in excellent agreement with the theoretical results; namely, that the effective coupling exists for surface waves whose phase velocity is equal to the speed of sound in air.

In regions where Rayleigh wave velocities vary with period due to layering in such a way that they are less than the speed of sound in air for short periods and exceed this value for longer periods, this coupling gives rise to a unique surface wave pattern on seismic records.

It is shown that body wave and surface wave character is almost independent of charge elevation in the range from 0 (on the ground) to 30 feet.

In a reciprocal manner ground roll from hole shots was recorded with air microphones as predicted by the theory.

INTRODUCTION

Recent experimental and theoretical studies reported in the literature[1,2] have shown that under certain conditions close coupling can exist between the atmosphere and surface waves of many types. When applied to Rayleigh waves, these results explain many of the characteristics of ground roll from hole shots and air shots. In particular, previously unexplained phenomena associated with air shooting methods are readily interpreted. Field conditions under which air shooting methods fail to produce significant changes in the character of ground roll can be predicted.

THEORY

An approximate theory of ground roll originating in an air shot can be given if the reaction of the Rayleigh wave on the air is neglected. In this case the air wave from the explosion can be treated simply as a pressure pulse traveling over the surface of a dispersive system. Theoretical results of Lamb[3] on the effect of a traveling disturbance can be applied. He represented a traveling disturbance by a succession of infinitesimal impulses applied at equal intervals of time at points

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† Lamont Geological Observatory (Columbia University), Palisades, New York.

‡ Consultant to Magnolia Petroleum Company, Dallas, Texas, during performance of field work reported in this paper.

[1] Frank Press, A. P. Crary, Jack Oliver, Samuel Katz, "Air Coupled Flexural Waves in Floating Ice," *Trans. Amer. Geophys. Union*, Vol. 32 (1935), 166–172.

[2] Frank Press, Maurice Ewing, "Theory of Air Coupled Flexural Waves," in press, *Journ. Appl. Phys.* (1951).

[3] H. Lamb, "Hydrodynamics," *Cambridge University Press, 6th Edition* (1932) 413–415.

along the path. Each impulse produces a train of waves, and superposition of all the wave trains results in reinforcement only for those waves (having a discrete frequency) whose phase velocity equals the speed of sound in air. Since energy associated with a given frequency is propagated with the corresponding group velocity, the wave system generated by an air shot consists of a train of constant frequency waves extending from the air wave arrival to the arrival time for waves traveling from the shot point with this group velocity. In a typical case the group velocity associated with the critical frequency is about half the speed of sound in air, so the surface waves begin with the air wave and have a duration about equal to the travel time. Thus, the approximate theory explains an outstanding feature of air shooting, that ground roll from an air shot is limited very often to the portion of the seismogram following the air wave, whereas, in a hole shot, ground roll covers the major part of the seismogram. If the phase velocity of Rayleigh waves in the ground never equals the speed of sound in air, resonant coupling cannot occur and ground roll from air and hole shots differ only through differences in the spectra of air shots and hole shots. Thus, in many regions having high velocity surface layers, the speed of Rayleigh waves exceeds the speed of sound in air for all periods, and the portion of a seismogram containing ground roll should not be as significantly altered by air shooting as in a region of low velocity surface material.

Further discussion requires a more extensive theory. In the derivations which follow we shall represent the weathered layer as a liquid and the subweathering rocks as a semi-infinite elastic solid. It is believed that this approximation is adequate to explain the atmospheric influence on ground roll with far less computation than for two solids for the following reasons: (1) In both cases the low frequency limit of phase velocity is the speed of Rayleigh waves in the bottom layer; (2) Setting the speed of compressional waves in the liquid layer equal to the speed of Rayleigh waves in the upper solid layer results in identical high frequency limits of phase velocity for both cases; (3) At intermediate frequencies phase and group velocity curves for the two cases are not significantly different.* It can be shown that an additional high frequency branch can exist for the two solid layer case in which phase velocity approaches the speed of compressional waves in the upper layer. This branch enters only as a higher mode and, as will be seen later, is associated with phase velocities much too high for resonant atmospheric coupling.

Consider the propagation of Rayleigh waves in a system consisting of an infinite atmosphere having density ρ_0, incompressibility λ_0, and sound velocity v_0 overlying a liquid layer of thickness H, having density ρ_1, incompressibility λ_1, and compressional wave velocity v_1. The liquid layer in turn overlies an elastic solid of infinite extent having density ρ_2, compressional wave velocity α_2, shear

* Recent calculations of air coupled Rayleigh waves for the case of a solid surface layer give almost identical results to those obtained using a liquid surface layer. This material will be published in another paper.

wave velocity β_2, and Lame's constants λ_2, μ_2. Poisson's constant for the solid layer is taken as 0.25 and we may write:

$$\begin{aligned} v_0^2 &= \lambda_0/\rho_0 \\ v_1^2 &= \lambda_1/\rho_1 \\ \alpha_2^2 &= (\lambda_2 + 2\mu_2)/\rho_2 \\ \beta_2^2 &= \mu_2/\rho_2 = \alpha_2^2/3. \end{aligned} \tag{1}$$

A Cartesian coordinate system is chosen with the x-axis in the air liquid interface parallel to the direction of propagation and the z-axis vertically downward,

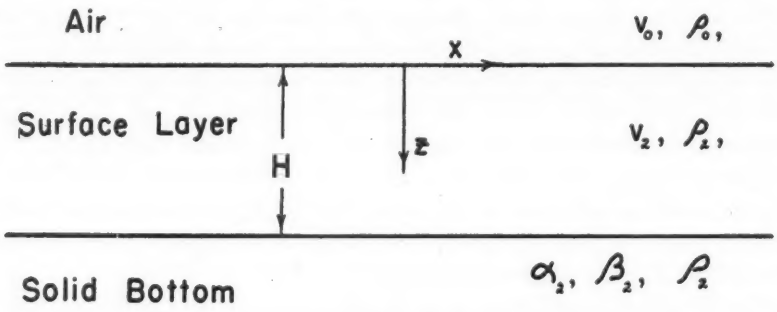

FIG. 1. Assumed surface layering.

shown in Figure 1. We denote displacements parallel to z and x by w and u respectively and the subscripts 0, 1, 2 hereafter refer to air, liquid, and solid layers respectively.

Following the mathematical procedure of Lamb[4] we introduce the functions $\phi(x, z, t)$ and $\psi(x, z, y)$ defined by the equations:

$$\left.\begin{aligned} u_i &= \partial\phi_i/\partial x \\ w_i &= \partial\phi_i/\partial z \end{aligned}\right\} \quad i = 0, 1 \tag{2}$$

$$\left.\begin{aligned} u_2 &= \partial\phi_2/\partial x + \partial\psi_2/\partial z \\ w_2 &= \partial\phi_2/\partial z - \phi\psi_2/\partial x \end{aligned}\right\}. \tag{3}$$

Expressing the vertical stress p_{zz} and the tangential stress p_{zx} in terms of ϕ,ψ and the elastic constants we can write:

$$p_{zz} = \lambda\nabla^2\phi + 2\mu(\partial^2\phi/\partial z^2 - \partial^2\psi/\partial x\partial z) \tag{4}$$

$$p_{zx} = \mu(\partial^2\psi/\partial z^2 - \partial^2\psi/\partial x^2 + 2\partial^2\phi/\partial x\partial z). \tag{5}$$

It is required that the functions ϕ and ψ satisfy the wave equations:

[4] H. Lamb, "On Elastic Waves in a Plate," *Proceedings of the Royal Society of London*, *A93* (1917), 114.

$$\partial^2\phi_i/\partial t^2 = v_i^2\nabla^2\phi_i \quad i = 0, 1 \tag{6}$$

$$\left.\begin{aligned}\partial^2\phi_2/\phi t^2 &= \alpha_2^2\nabla^2\phi_2\\ \partial^2\psi_2/\partial t^2 &= \beta_2^2\nabla^2\psi_2\end{aligned}\right\} \tag{7}$$

and the boundary conditions:

$$(p_{zz})_0 = (p_{zz})_1 \quad \text{at} \quad z = 0 \tag{8}$$

$$w_0 = w_1 \quad \text{at} \quad z = 0 \tag{9}$$

$$(p_{zz})_1 = (p_{zz})_2 \quad \text{at} \quad z = H \tag{10}$$

$$(p_{zx})_2 = 0 \quad \text{at} \quad z = H \tag{11}$$

$$w_1 = w_2 \quad \text{at} \quad z = H. \tag{12}$$

It can readily be verified that a set of solutions of (6) and (7) are of the form:

$$\phi_0 = Ae^{\eta_0 z}e^{i(kx-\omega t)} \tag{13}$$

$$\phi_1 = [B \sin(\eta_1 z) + C \cos(\eta_1 z)]e^{i(kx-\omega t)} \tag{14}$$

$$\phi_2 = De^{-\eta_2 z}e^{i(kx-\omega t)} \tag{15}$$

$$\psi_2 = Ee^{-\zeta_2 z}e^{i(kx-\omega t)} \tag{16}$$

where:

$$\left.\begin{aligned}\eta_0^2 &= k^2 - \omega^2/v_0^2 = k^2\left(1 - \frac{c^2}{v_0^2}\right)\\ \eta_1^2 &= \omega^2/v_1^2 - k^2 = k^2\left(\frac{c^2}{v_1^2} - 1\right)\\ \eta_2^2 &= k^2 - \omega^2/\alpha_2^2 = k^2\left(1 - \frac{c^2}{\alpha_2^2}\right)\\ \zeta_2^2 &= k^2 - \omega^2/\beta_2^2 = k^2\left(1 - \frac{c^2}{\beta_2^2}\right)\end{aligned}\right\} \tag{17}$$

and k is the wave number related to wavelength L (measured in the direction of x) by $k = 2\pi/L$ and to phase velocity c by

$$c = \omega/k. \tag{18}$$

In equations 13–16, ϕ_0, ϕ_1, ϕ_2, ψ_2 define a system of waves propagating in the x direction with phase velocity c; ϕ_0, ϕ_1, ϕ_2 represent compressional wave components and ψ_2 represents a distortional wave component. We will be interested in the two cases $\beta_2 \geqq v_0 \geqq c \geqq v_1$ and $\beta_2 \geqq c \geqq v_0 \geqq v_1$, which represent the conditions of a low speed surface layer. In the first case all η's and ζ are real, wave amplitudes decrease exponentially with distance from the surface layer and the solutions represent undamped wave guide propagation through the surface layer.

In the second case η_0 is imaginary, ϕ_0 is finite at infinite distances from the surface layer indicating energy radiation from the surface layer into the air.

If (13)–(16) are substituted in the boundary conditions (8)–(12), five independent homogeneous equations in the amplitude factors A, B, C, D, E are obtained. Any four of these five factors can be found in terms of the fifth, but for a solution to exist the determinant formed by the coefficients of the five factors in the homogeneous set of equations must vanish. This amounts to eliminating the wave amplitude factors between the five boundary equations. Performing this operation we obtain the frequency equation which can be written as follows after some simplification:

$$\tan\left(kH\sqrt{c^2/v_1^2-1}\right)$$
$$-\frac{\rho_2}{\rho_1}\frac{\beta_2^4}{c^4}\frac{\sqrt{c^2/v_1^2-1}}{\sqrt{1-c^2/\alpha_2^2}}\left[4\sqrt{1-\frac{c^2}{\alpha_2^2}}\sqrt{1-\frac{c^2}{\beta_2^2}}-\left(2-\frac{c^2}{\beta_2^2}\right)^2\right]$$
$$+\frac{\rho_0\sqrt{\frac{c^2}{v_1^2}-1}}{\rho_1\sqrt{1-\frac{c^2}{v_0^2}}}\left\{\frac{\rho_2}{\rho_1}\frac{\beta_2^4}{c^4}\frac{\sqrt{\frac{c^2}{v_1^2}-1}}{\sqrt{1-\frac{c^2}{\alpha_2^2}}}\left[4\sqrt{1-\frac{c^2}{\alpha_2^2}}\sqrt{1-\frac{c^2}{\beta_2^2}}\right.\right.$$
$$\left.\left.-\left(2-\frac{c^2}{\beta_2^2}\right)^2\right]\tan\left(kH\sqrt{\frac{c^2}{v_1^2}-1}\right)+1\right\}=0. \qquad (19)$$

As a check on Equation (19) we see that for $\rho_0=0$ it reduces to the frequency equation for Rayleigh waves propagated in a liquid layer overlying a semi-infinite elastic solid, for $\rho_0=\rho_1=0$ it reduces to Rayleigh waves in the solid, and for $\rho_2=0$ it reduces to the frequency equation for compressional waves propagating through two liquid layers.

Equation (19) defines an implicit relationship between frequency $f=ck/2\pi$ and phase velocity c with the elastic constants of the system as parameters. Since ρ_0/ρ_1 is of order of 0.001, the third term in the equation which gives the effect of the atmosphere is negligible *except* in the region c close to v_0. For $\beta_2 \geqq v_0 \geqq c \geqq v_1$ real values of k and c satisfying (19) can be found. For c real and $\beta_2 \geqq c > v_0$ the first and second terms of (19) are real, the third term is imaginary, hence their sum can never vanish. Actually it can be shown that for this range of values of c the effect of the third term is to add a very small imaginary component to the real values of c determined by neglecting the third term, except, of course, when c is close to v_0 and the imaginary component becomes large. Complex values of phase velocity correspond to radiation of energy into the atmosphere, the amount of radiation increasing with the magnitude of the imaginary component.

Equation (19) was used to compute k as a function of c for the case

$\rho_2/\rho_1 = 1.1$, $\rho_0/\rho_1 = 0.001$, $\alpha_2 = \sqrt{3}\,\beta_2$, $\beta_2 = 2.5v_1$, $v_0 = 1.4v_1$.

which were chosen as the most typical values for weathered layers. Group velocity was computed by numerical differentiation using the equation:

$$U = c + k\frac{dc}{dk}. \tag{20}$$

Results of these computations are presented in dimensionless form in Figure 2, where c/v_1 and U/v_1 are plotted against kH for the lowest mode of vibration. The dimensionless parameter kH is proportional to frequency through the equa-

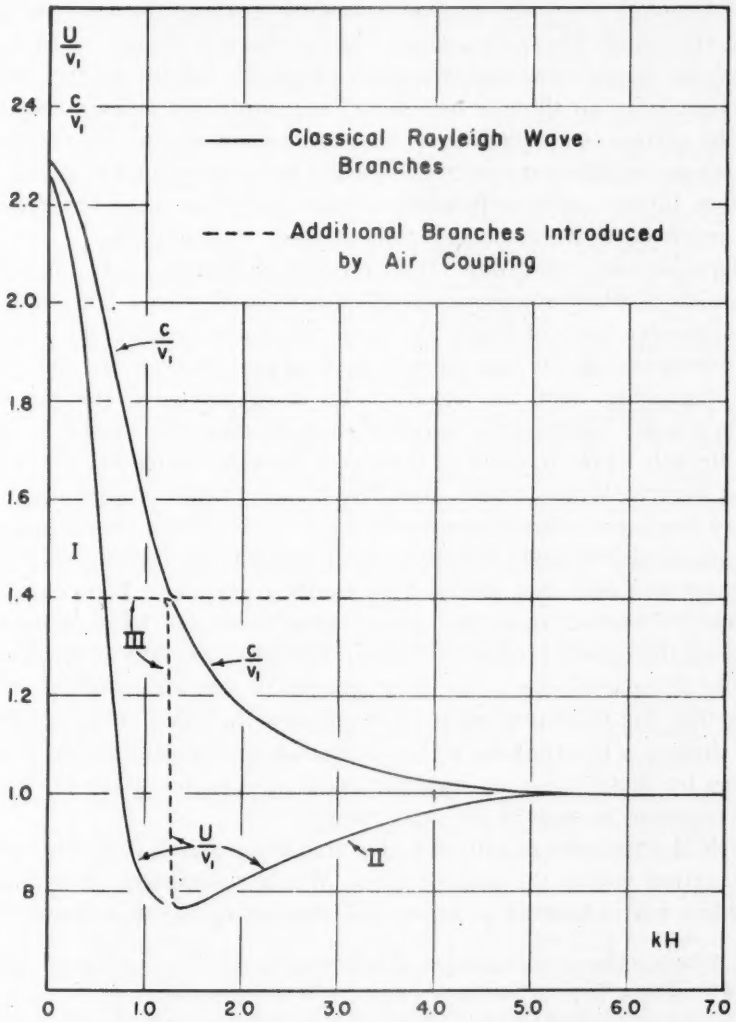

FIG. 2. Phase and group velocity of air coupled Rayleigh waves.

tion $f=(c/v_1)kH/2\pi(H/v_1)$. The heavy lines in Figure 2 show where atmosphere influence is negligible and the dashed lines are new branches introduced by air coupling.

It is well known that in a dispersive medium such as the one under consideration, the sequence of waves arriving at a given point can be obtained from a group velocity curve such as that presented in Figure 2. For discussion of the amplitudes of waves corresponding to the different branches of the group velocity curve, one must derive the excitation functions for hole shots and air shots. These functions relate wave amplitudes to the position of the source and the frequency spectrum of the pulse which it emits. (See for example, Pekeris[5] or Press and Ewing.[6]) Although the mathematical procedure is straightforward the computations are very long. Thus, the group velocity curve of Figure 2 can be used to determine the arrival time and frequency of ground roll for sources in any part of the system (e.g., air shots or hole shots) as recorded by pickups located in any part of the system (e.g., geophones or air microphones) but the relative amplitudes of waves for different source and pickup locations cannot be given. Existing calculations for air coupling to another type of surface wave (reference 2) can be used, however, to infer something about relative amplitudes.

We have divided the group velocity curve of Figure 2 into branches I, II, and III, each of which represents a different train of waves. Branch I accounts for the dispersive train of Rayleigh waves usually associated with ground roll. Waves corresponding to this branch first appear as low frequency arrivals ($kH\approx 0$) travelling with the speed of Rayleigh waves in the bottom layer ($U\approx 2.3v_1=.92\beta_2$). Subsequent arrivals show a gradual increase in frequency since in Branch I kH increases as the group velocity decreases. The wave train continues to arrive with increasing frequency until a time corresponding to propagation at a minimum value of group velocity $U\approx .78v_1$. From the analogous theory referred to above we would expect waves propagated according to Branch I to predominate for a hole shot recorded by a surface geophone. Note that the lower group velocity waves propagated according to Branch I have phase velocities approaching the speed of sound in air from the side $c>v_0$. These waves are therefore highly attenuated due to the large imaginary component of phase velocity. The fact that the minimum value of group velocity has a corresponding phase velocity close to v_0 is fortuitous in that it depends on the values of β_2/v_1 and v_0/v_1. Our values for these constants, however, seem most representative of field conditions encountered in most of the experiments.

Branch II represents a train of higher frequency waves controlled essentially by propagation within the surface layer. Waves propagated according to this branch have been observed at sea where the surface layer is water, but have

[5] C. L. Pekeris, "Theory of Propagation of Explosive Sounds in Shallow Water," in *Propagation of Sound in the Ocean, Mem. 27*, Geological Society of America (1948).

[6] Frank Press and Maurice Ewing, "Propagation of Explosive Sound in a Liquid Layer Overlying a Semi-Infinite Elastic Solid," *Geophysics, Vol. XV, No. 3* (1950), 426–446.

never been observed on land. It is probable that water, having excellent elastic properties, transmits these high frequency waves freely, whereas, the poorly elastic surface weathered layer absorbs and scatters most of the higher frequency energy.

Branch III results from coupling of the ground roll to atmospheric compressional waves. Waves propagated according to this branch begin abruptly with the arrival of the air wave ($U=1.4v_1$, $0 \leqq kH \leqq 1.2$) and are followed by a train of constant frequency waves ($kH \approx 1.25$), having constant phase velocity $c=v_0$ and lasting until the time corresponding to propagation at the value of group velocity $U=.78v_1$ found when $kH \approx 1.25$. Note that the single frequency of the waves following the air pulse is identical to that of the ground roll whose phase velocity equals the speed of sound in air—in agreement with the approximate theory. From the results of the analogous theory of flexural waves (reference 2), we would expect waves propagated according to Branch III to predominate for air shots recorded by surface geophones and reciprocally for hole shots recorded by air microphones. From Equations (13) and (17), we note that the amplitude of the air motion decreases with height above the surface as $e^{-kz\sqrt{1-c^2/v_0^2}}$. It can be shown in a reciprocal manner that for shots in the air, all amplitudes decrease as $e^{-kd\sqrt{1-c^2/v_0^2}}$, where d is the height of the shot point above the surface. Since $c=v_0$ for the constant frequency wave train propagated according to Branch III, it follows that the amplitude of these waves is independent of the height of the air charge above the surface, as long as d/L is finite and $d \ll$ shot-detector distance. We may summarize our theoretical results as follows:

1. For a hole shot in a layered medium such as that postulated a geophone records ground roll as an orderly sequence of dispersive Rayleigh waves.
2. For a hole shot an air microphone records a constant frequency train of waves following the abrupt arrival transmitted with the speed of sound in air.
3. Ground roll from an air shot recorded by a geophone predominates after the arrival of the direct air wave, and then only as a train of waves having constant frequency and phase velocity. The character of the seismogram after the arrival of the air wave is independent of the height of the charge above the surface.
4. The different wave trains described all arise from a single source. Multiple charges can be represented by superposition of the wave trains originating in each source to the extent that non-linear effects are negligible.
5. Dispersive Rayleigh waves can be produced by propagation in a medium having a gradual increase in shear velocity with depth. Although the exact theory has not been worked out one would expect air coupling results analogous to the layer theory.
6. In areas where a high speed surface layer occurs such that the Rayleigh wave velocity in the surface layer exceeds the speed of sound in air, coupling of ground roll to the air cannot exist. One would therefore expect only minor differences in ground roll from air shots and hole shots—these originating in differences in the source spectra for the two types of shots.

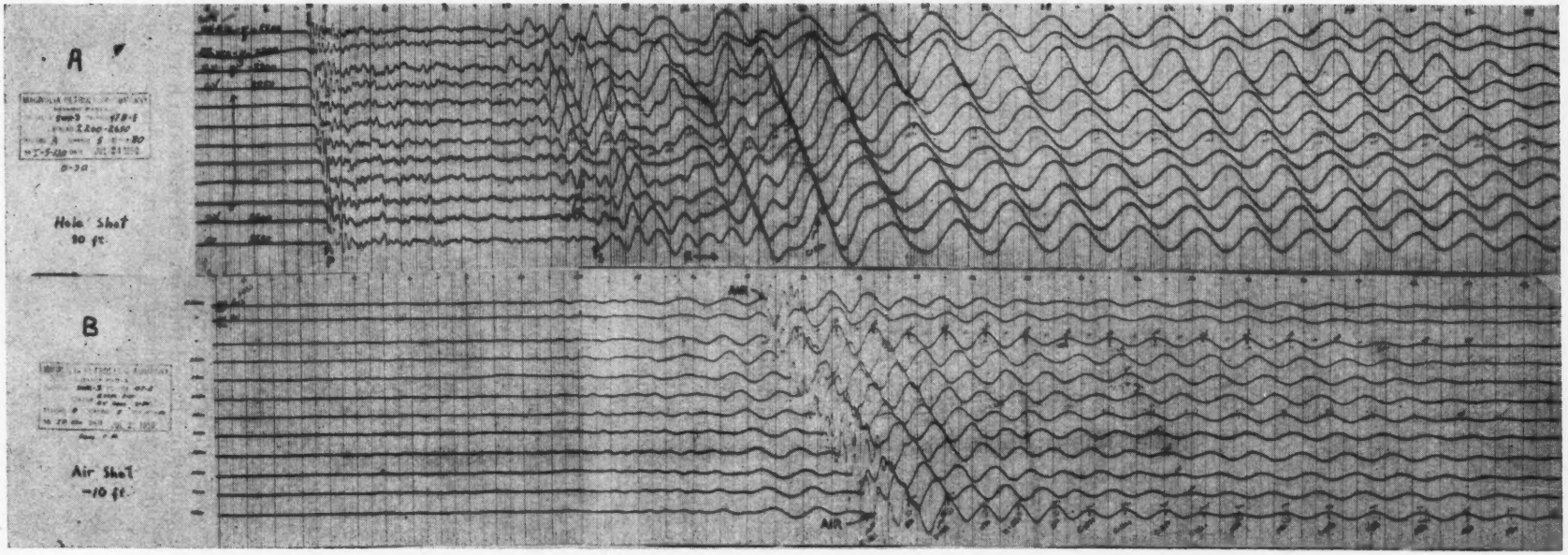

FIG. 3. Contrast between ground roll from a ground shot (A) and an air shot (B).

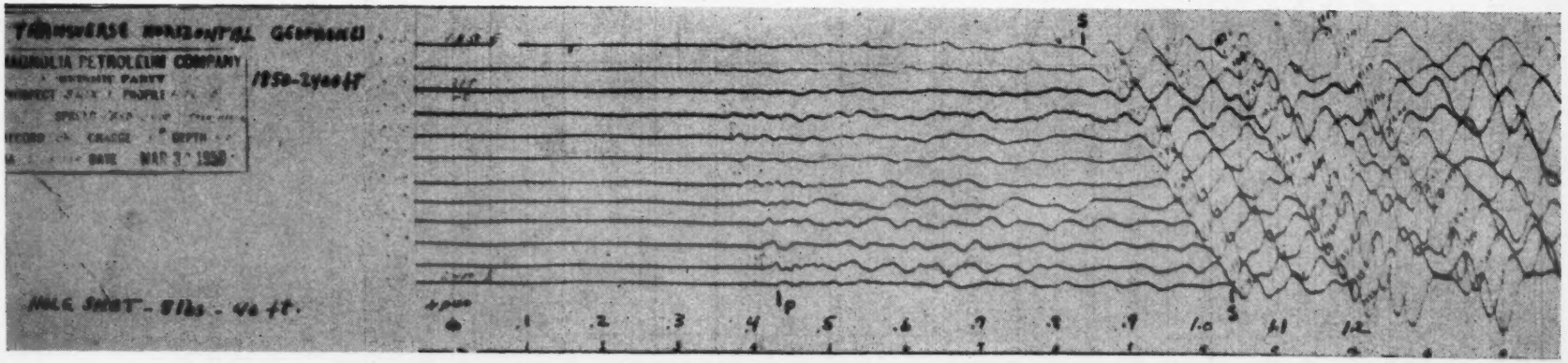

FIG. 4. S Waves recorded on a transverse horizontal geophone spread 1,850–2,400 ft. from a hole shot.

EXPERIMENTAL RESULTS

In the course of a series of field experiments on surface waves, sufficient data were obtained to provide striking verification of the theoretical results. In general it was found that agreement was best in areas where ground roll from a hole shot appeared as an orderly sequence of dispersive Rayleigh waves.

In Figures 3, 6, 7, single 5-pound charges where detonated in holes, on the ground and in the air as specified on each record. Spread distance was 2,200–2,650

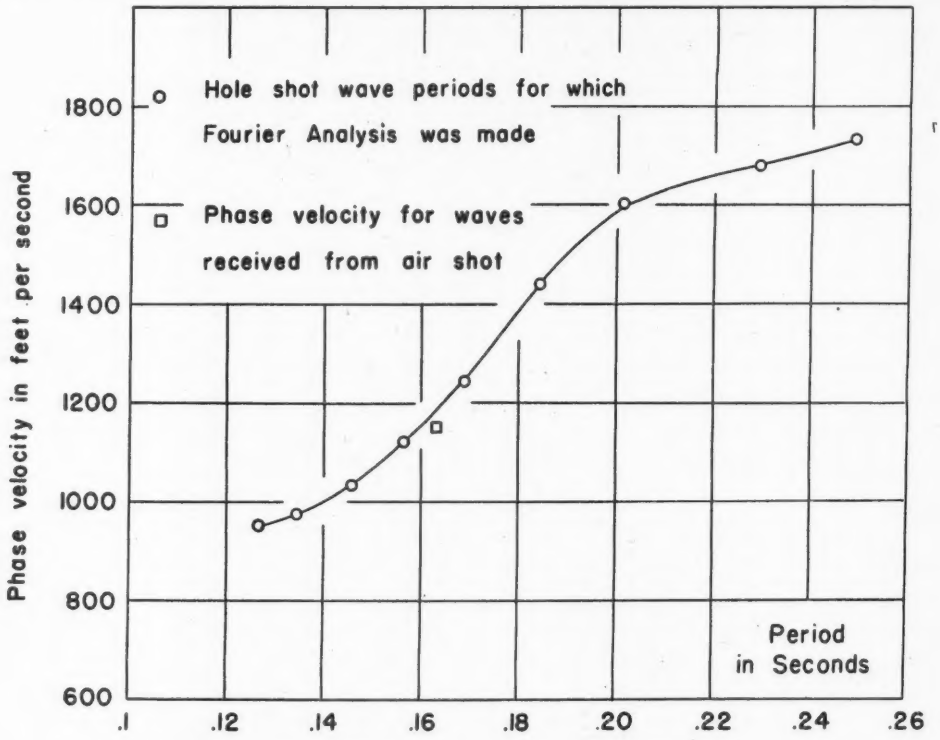

FIG. 5. Phase velocity curves for hole shot and air shot by Fourier analysis of records at 800 feet and 1,200 feet.

feet and the first three traces are reception at 2,200 feet from (1) radial horizontal; (2) a trace (spurious due to a recording error) originally intended to be transverse horizontal; and (3) vertical geophone. Succeeding traces are vertical geophones located at 50-foot intervals.

Wide band amplifiers passing 5–220 cps were used with integrating circuits to give ground displacement.

Figure 3 contrasts the ground roll from a hole shot (A) and an air shot (B) at the same shot point. Refracted compressional waves (*P*) and waves tentatively identified as shear (*S*) are followed by dispersive Rayleigh waves (*R*) in the hole shot record.

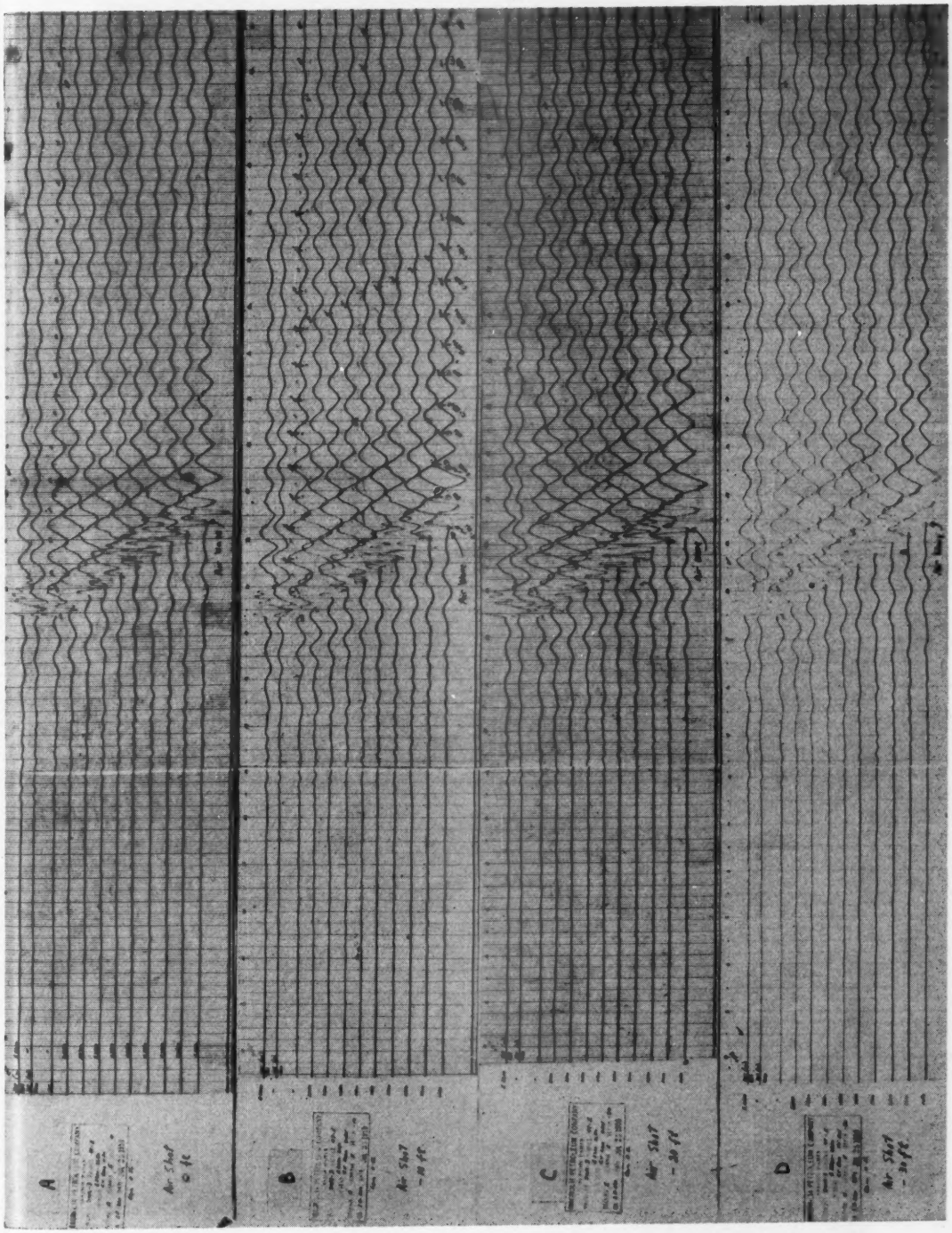

FIG. 6. Ground roll air shots at various heights.

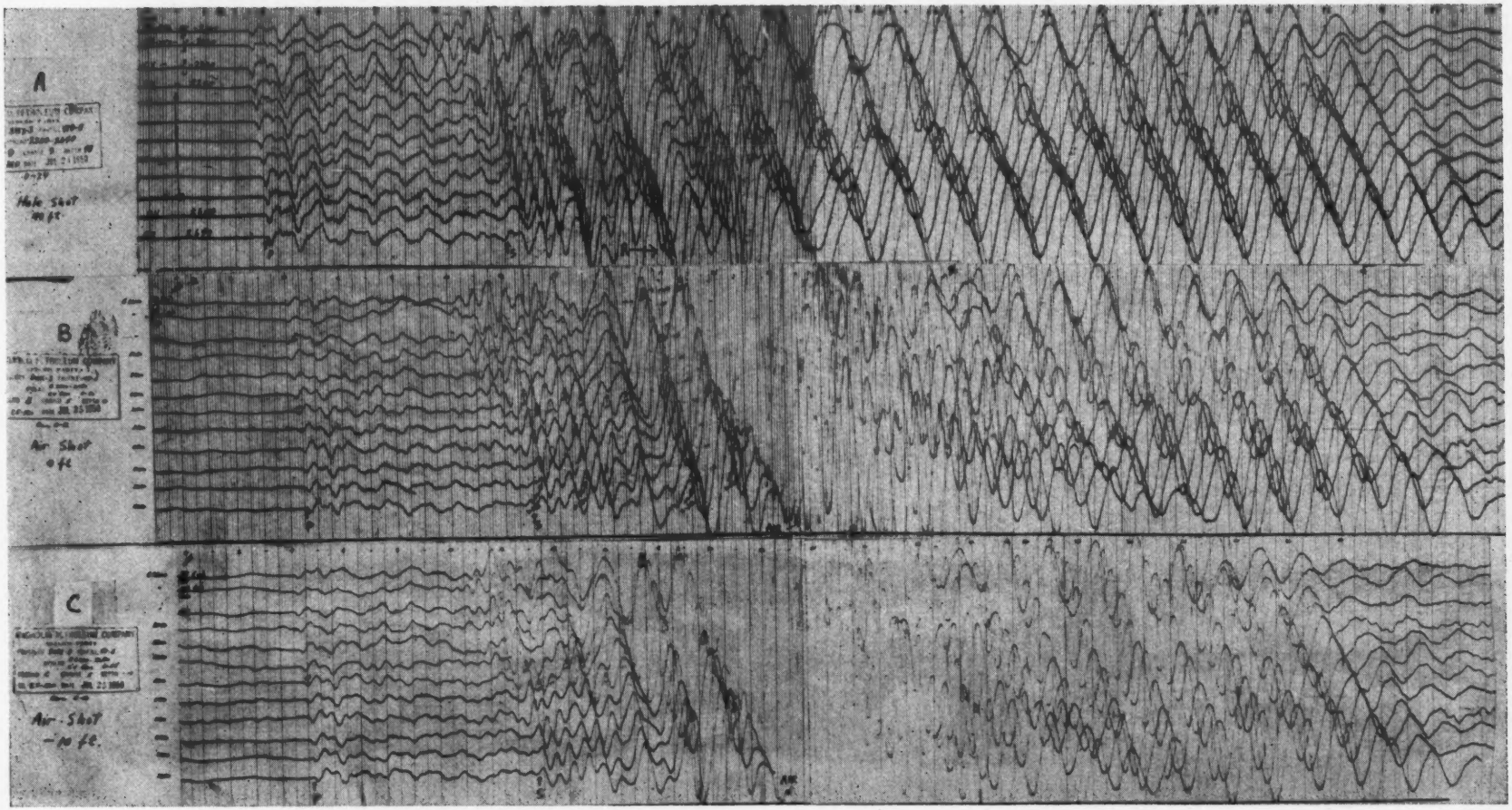

FIG. 7. Comparison of body waves and surface waves from hole shot (A), single air shots (B and C).

The main evidence in favor of identifying the second group as shear waves is (1) the large transverse component in these waves as shown in Figure 4 which consists of a transverse horizontal spread 1,850–2,400 feet; (2) the agreement of velocity with borehole determinations. A difficulty with this interpretation is the improper phase relationship between the vertical and radial horizontal geophone at 2,200 feet as shown in Figures 3A, 7B, and 7C. Additional study of these waves is needed.

The Rayleigh waves are identified on the basis of their retrograde elliptical motion, their characteristic dispersion, and their low velocity. In many cycles the axis of the elliptical orbit is inclined with the vertical, a phenomenon also observed by Howell.[7]

Ground roll on the air shot record consists of relatively constant frequency Rayleigh waves immediately following the direct air wave. The phase velocity of these waves remains reasonably close to the speed of sound in air for about 6 cycles, and thereafter increases erratically by about 30 per cent. With the use of a Fourier analyzer phase velocity was obtained as a function of frequency for the dispersive Rayleigh waves. These results are shown in Figure 5 for records obtained at 800 feet and 1,200 feet. It was found that the frequency of waves whose phase velocity equalled the speed of sound in air agreed with the frequency of the waves following the air pulse on the air shot records. The characteristics of ground roll for air shots and hole shots thus bear out our theoretical results.

Figure 6 shows the effect of elevation of charge on the character of ground roll for an air shot, all other factors including amplifier gain remaining the same. It is seen that record character remains unchanged for shot heights ranging from 0–30 feet, as predicted by the theoretical results.

Figures 7B and 7C are records of air shots detonated at elevation of 0 feet and 10 feet and recorded at higher gains than the previous air shot records. The constant frequency Rayleigh waves following the air wave are almost off scale. The predominant disturbances preceding the air waves are P and $S(?)$ type body waves. Note that the body waves are almost identical for the two shots suggesting that energy transfer into body waves is not critically dependent on the elevation of an air shot. Comparison with the hole shot in Figure 7A shows that the character of the body waves from the hole shots and the air shots are similar. From records obtained with different spreads here and at other locations we conclude that the ratio of surface waves to body waves after the time necessary for the air wave to arrive is many times greater for an air shot than for a hole shot of identical charge size at the same location.

On many occasions microphones several feet above the ground recorded constant frequency air coupled waves from hole shots, providing a convincing verification of the theoretical results given in the previous section.

[7] B. F. Howell, Jr., "Ground Vibrations Near Explosions," *Bull. S.S.A.*, *Vol. 39* (1949), 285–310.

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(Lamont Geological Observatory Contribution No. 32)

AN ELECTROMAGNETIC INTERPRETATION PROBLEM IN GEOPHYSICS

L. B. SLICHTER*

ABSTRACT

An interpretation problem in electromagnetic prospecting is discussed. A flat earth in which the three electrical properties of material vary only with depth is subjected to an alternating inducing field produced by a dipole above the surface with axis perpendicular to the surface. Observations of the horizontal or of the vertical component of the magnetic intensity at the ground's surface are supposed to be available at all distances. From these observations solutions for the three unknown functions are developed. When the magnetic permeability is variable, the solutions for the permeability and dielectric functions require observations at two different frequencies. The conductivity function may be found from observations at a single frequency.

It is shown that the horizontal and vertical components of the magnetic field intensity are mutually dependent in the region above the ground's surface; and formulae independent of the ground's characteristics are deduced for expressing $H_\rho(\rho, z_i)$ in terms of $H_z(\rho, z_i)$, and vice-versa. Here $z=z_i \leqq h$ denotes a plane coincident with or above and parallel to, the earth's surface.

Partial List of Notations, in Order of Use

(Rationalized MKS units used throughout)

μ = Permeability
σ = Conductivity
ϵ = Inductive capacity
H = Magnetic field intensity
E = Electric field intensity
B = Flux density
λ = auxiliary length "unit," in meters = geometric scale factor
τ = auxiliary time "unit," in seconds = time scale factor
ω = angular frequency
$s(z) = \lambda^2\omega\mu\sigma$ (dimensionless), $\bar{s} \equiv \lambda^2\omega\bar{\mu}\bar{\sigma}$
$e(z) = \lambda^2\omega^2\mu\epsilon$ (dimensionless), $\bar{e} \equiv \lambda^2\omega^2\bar{\mu}\bar{\epsilon}$
a = radius of source
ρ, ϕ, z = cylindrical coord. system
h = height of source above surface
D = thickness of layer of variable properties
$H = D+h$
l^2 = dimensionless "separation" parameter
$k_0^2 = \lambda^2\omega^2\epsilon_0\mu_0, \quad \bar{k}^2 \equiv \bar{e} + i\bar{s}$
$K_0 = (l^2-k_0^2)^{1/2}$ for $l > k_0, \quad = i(k_0^2-l^2)^{1/2}$ for $l < k_0$
$\overline{K} \equiv (l^2-\bar{k}^2)^{1/2} = 2^{-1/2}\left[\left\{(l^2-\bar{e})^2+\bar{s}^2\right\}^{1/2} + \left|l^2-\bar{e}\right|\right]^{1/2} - i2^{-1/2}\left[\left\{(l^2-\bar{e})^2+\bar{s}^2\right\}^{1/2} - \left|l^2-\bar{e}\right|\right]^{1/2}$
Z_i, Z_i are functions of z and l
$m(\rho)$ = surface density of current in source
A_i, B_i = constants, independent of ρ, or z.

* Director, Institute of Geophysics, University of California. This paper represents in part results of investigations sponsored by the Geological Society of America's special Committee on Geophysical Research.

INTRODUCTION

In a previous paper (*Physics*, Dec. 1933), the author discussed an interpretation problem (or "inverse boundary-value" problem) in electrodynamics, for a flat earth whose conductivity and specific dielectric capacity were unknown functions of the depth. The excitation field was assumed to be produced by an oscillating magnetic dipole on the ground's surface, with axis vertical. Series solutions for the variation of the conductivity and dielectric capacity with depth were obtained by a method due to Langer from the values of the magnetic vector at the ground's surface. Using the same general method, the present study develops a simpler form of the series solution and extends results to include the case in which the permeability, μ, as well as the conductivity, σ, and dielectric constant, ϵ, each varies in an unknown, continuous manner with depth.

When, as is usually assumed, ϵ and μ are independent of the field intensities, Maxwell's equations for either a homogeneous or non-homogeneous isotropic medium are, in rationalized MKS units—

$$\nabla \times H = \sigma E + \epsilon \frac{\partial E}{\partial t} \tag{1}$$

$$\nabla \times E = -\partial B/\partial t = -\mu \frac{\partial H}{\partial t} \tag{2}$$

$$\nabla \cdot B = 0 \tag{3}$$

$$\nabla \cdot (\epsilon E) = 0 \tag{4}^*$$

where for the present, ϵ, μ and σ are assumed to be continuous functions of x, y and z, and independent of time. Upon eliminating $\partial H/\partial t$ between equations (1) and (2), one obtains—

$$\nabla \times \nabla \times E = \mu^{-1}\nabla\mu \times \nabla \times E - \mu\sigma \frac{\partial E}{\partial t} - \mu\epsilon \frac{\partial^2 E}{\partial t^2}. \tag{5}$$

SIMILITUDE, MODELS, AND THE DIMENSIONLESS PROPAGATION CONSTANT

Because of the large range of the size or scale factor encountered in geophysical applications, it is advisable to reduce eq. (5) and its associated eqs. (3) and (4) to dimensionless form. This is done by introducing the dimensionless coordinate system $\bar{x}$, $\bar{y}$, $\bar{z}$, $\bar{t}$ defined by

$$x = \lambda\bar{x}, \quad y = \lambda\bar{y}, \quad z = \lambda\bar{z}, \quad t = \tau\bar{t} \tag{6}$$

where λ and τ are auxiliary "units" of length and time, measured in meters and seconds respectively, but not necessarily of unit value. One thus obtains—

* The right member of eq. (4) is zero, since there can be no permanent distribution of charge in a conductor (Stratton, p. 15).

$$\bar{\nabla} \times \bar{\nabla} \times E = \mu^{-1}\bar{\nabla}\mu \times \bar{\nabla} \times E - \lambda^2\tau^{-1}\mu\sigma \frac{\partial E}{\partial \bar{t}} - \lambda^2\tau^{-2}\mu\epsilon \frac{\partial^2 E}{\partial \bar{t}^2} \tag{7}$$

$$\bar{\nabla} \cdot B = 0 \tag{8}$$

$$\bar{\nabla} \cdot (\epsilon E) = 0 \tag{9}$$

where the notations $\bar{\nabla}$ denote operations with respect to the dimensionless variables $\bar{x}$, $\bar{y}$, $\bar{z}$. Since the ratio $\mu^{-1}\bar{\nabla}\mu$ is dimensionless, as are the coordinate numbers $\bar{x}$, $\bar{y}$, $\bar{z}$, it is evident that the quantities

$$S_1 \equiv -\lambda^2\tau^{-1}\mu\sigma \quad \text{and} \quad S_2 \equiv -\lambda^2\tau^{-2}\mu\epsilon$$

in eq. (7) must also be dimensionless. The invariance of the quantities S_1 and S_2 to changes of the dimensional multipliers or "scale factors" λ and τ is the necessary and sufficient condition for electrodynamic similitude* (Stratton, p. 489).

When the time variation is harmonic, introduction of the common factor $e^{-i\omega\tau\bar{t}}$ in eq. (7), yields a modified form of the dimensionless functions S_1 and S_2, expressed in terms of the angular frequency ω instead of the time unit τ. Thus—

$$S_1 \to i\lambda^2\omega\mu\sigma \equiv is, \qquad S_2 \to \lambda^2\omega^2\mu\epsilon \equiv e. \tag{10}$$

In this case the condition for similitude is the invariance of the complex number

$$k^2 = \lambda^2\omega^2\mu\epsilon + i\lambda^2\omega\mu\sigma \equiv e + is. \tag{10a}$$

This number is the square of the so-called "propagation constant," k, written in dimensionless form. Dimensionless coordinates and the dimensionless form of the propagation constant corresponding to eq. (10a) will be adopted henceforth.

The ratio $e/s = \omega\epsilon\sigma^{-1}$ is usually very small in geophysical applications. For example when $\sigma^{-1} = 1$ ohm meter, and $\epsilon = 8.854 \times 10^{-11}$ farads/meter (namely 10 times its free-space value) and $\omega/2\pi = 10{,}000$ cycles/sec., then the ratio is about 5.5×00^{-6}. Similitude may therefore usually be satisfactorily attained by maintaining the product $\lambda^2\omega\mu\sigma$ invariant; and because of the inconvenience in controlling μ, this is generally accomplished by adjusting the product $\omega\sigma$ to the scale change represented by the value of λ. However, it will not in general be assumed that displacement currents, and hence the ratio e/s, are negligible.

* These conditions follow at once from the concept of a "scale-model" and the uniqueness (Stratton, pp. 486–488) of the solution of the electromagnetic problem. We define a "prototype" coordinate system, $\lambda_p\bar{x}_p, \cdots, \tau_p\bar{t}_p$, and a "model" coordinate system $\lambda_m\bar{x}_m, \cdots, \lambda_m\bar{t}_m$, as follows: In the prototype frame of reference, the units of length and time are one meter and one second. In a model system, at least one of these dimensional multipliers, λ_m or τ_m (when measured in meters or seconds), differs from unity. If the number S_1 in a prototype system and in a model is the same function of the prototype and model coordinate numbers, $\bar{x}_p, \cdots, \bar{t}_p$, and $\bar{x}_m, \cdots, \bar{t}_m$ respectively, and similarly for the quantity S_2, then the differential equations (7), (8) and (9), for the two systems are clearly identical. If in addition the respective boundary conditions at $\bar{t}_p = \bar{t}_m = 0$ are identical, one concludes from the known uniqueness of the problem that the electromagnetic field at "corresponding points" (i.e., points having the same coordinate numbers $\bar{x}_m = \bar{x}_p, \cdots, \bar{t}_m = \bar{t}_p$) are identical. Such systems are said to be "electrodynamically similar."

STATEMENT OF THE PROBLEM

Figure 1 is descriptive of the problem under consideration. In the source S, which is represented in the figure by a single circular current loop, the intensity of the current may, however, vary as a function of the radial distance in any suitable manner. The source current oscillates in uniform time-phase at frequency $\omega/2\pi$, and is confined to a disk of finite radius a, which is parallel to and at height h above the surface of a flat isotropic earth. Within a layer extending from the surface to depth D, the three electrical properties of material are supposed to be

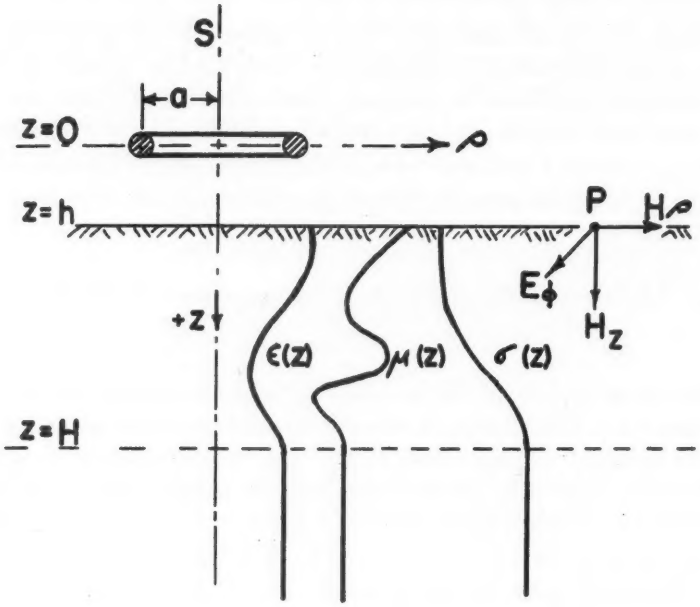

FIG. 1

unknown continuous (and finite) functions of the depth alone; but at depth D they attain the constant values $\bar{\mu}$, $\bar{\sigma}$, $\bar{\epsilon}$, respectively. The axis of symmetry passing through the center of the source-disk normal to the ground's surface is chosen as the z axis (positive downwards) of a right-hand cylindrical coordinate system ρ, ϕ, z, with origin at the center of the disk.

By virtue of symmetry, the component H_ϕ of the magnetic vector is everywhere zero, as are the components E_ρ and E_z of the electric vector. Accordingly, the subscript in E_ϕ will be omitted for simplicity. The intensities and phases of the components H_ρ and H_z are regarded as observable on the ground's surface at all distances ρ. The problem is the determination of the three unknown functions of z alone, σ, ϵ, and μ, in the range $h \leqq z \leqq D+h \equiv H$.

THE ORDINARY DIFFERENTIAL EQUATIONS FOR THE PROBLEM

Since dimensionless coordinates $\bar{\rho}$, $\bar{\phi}$, $\bar{z}$, $\bar{t}$ will henceforth be used exclusively, the "bars" will be understood to be omitted. By virtue of the symmetry conditions mentioned, eq. (7) becomes, in the cylindrical coordinate system,

$$\frac{\partial^2 E}{\partial z^2} - \mu^{-1}\frac{\partial \mu}{\partial z}\frac{\partial E}{\partial z} + \frac{\partial^2 E}{\partial \rho^2} + \frac{1}{\rho}\frac{\partial E}{\partial \rho} - (\rho^{-2} - e - is)E = 0 \tag{11}$$

which is separated into the two ordinary differential equations

$$\frac{d^2 r}{d\rho^2} + \rho^{-1}\frac{dr}{d\rho} + (l^2 - \rho^{-2})r = 0 \tag{12}$$

$$\frac{d^2 Z}{dz^2} - \mu^{-1}\frac{d\mu}{dz}\frac{dZ}{dz} - (l^2 - e - is)Z = 0 \tag{13}$$

by the usual type of substitution, $E = r(\rho)Z(z)$. Here the abbreviations defined in eq. (10) have been incorporated. The arbitrary dimensionless parameter l^2 is chosen to be real and positive (or zero).

Because the diameter of the source, the thickness of the layer, and the values of its electrical properties are all finite, the effect of this layer upon the electromagnetic field observed at distant points (i.e. $\rho >> H$, $\rho >> h$) is equivalent merely to a modification of the intensity and phase of the source. Thus at large distances the layer introduces a constant factor in the field intensities, and the electromagnetic field is essentially the same as that for an equivalent magnetic oscillator on the surface of a uniform earth of electrical constants $\bar{\sigma}$, $\bar{\epsilon}$, $\bar{\mu}$. In the finite region of present interest, where the observed field is significantly influenced by the presence of the superficial layer, steady-state conditions may be assumed to exist, and the problem may be treated as a standing wave problem. Hence the appropriate solution of the Bessel's equation (12), which remains finite at the origin, is $J_1(l\rho)$.

THE ELEMENTARY SOLUTIONS IN z

In the four regions separated by the planes $z = 0$, $z = h$, and $z = H$, the appropriate elementary solutions of eq. (13) are, respectively—

A. When $z \leqq 0$,

$$Z_1 = A_1(l) \exp K_0 z \tag{14}$$

where

$$K_0 \equiv (l^2 - k_0^2)^{1/2}, \qquad l > k_0 \tag{15}$$

$$\equiv -i(k_0^2 - l^2)^{1/2}, \qquad l < k_0$$

$$k_0^2 \equiv \lambda^2\omega^2\epsilon_0\mu_0$$

$$\epsilon_0 = 8.854 \times 10^{-12} \text{ farad/meter}$$

$$\mu_0 = 4\pi \times 10^{-7} \text{ henry/meter}$$

(i.e. the free-space values of these quantities). With the above choice of signs, the elementary solution represents a wave propagated upwards when $l^2 < k_0^2$; and, when $l^2 > k_0^2$, a standing wave whose amplitude diminishes exponentially in the negative z direction.

B. In the layer of (dimensionless) thickness h between the source and the ground's surface, the general solution of eq. (13) may be written

$$Z_2 = A_2(l) \cosh K_0 z + B_2(l) \sinh K_0 z \qquad 0 \leqq z \leqq h \tag{16}$$

C. Within the layer of unknown properties, two linearly independent (unknown) solutions of eq. (13) will be formally designated by $\mathfrak{Z}_1(l, z)$ and $\mathfrak{Z}_2(l, z)$; the general solution, Z_3, may then be written—

$$Z_3 = A_3 \mathfrak{Z}_1 + B_3 \mathfrak{Z}_2, \qquad h \leqq z \leqq H. \tag{17}$$

D. At depths greater than H, the appropriate solution is—

$$Z_4 = A_4 \exp(-\bar{K} z), \qquad H \leqq z \tag{18}$$

where

$$\bar{k}^2 \equiv \lambda^2 \omega^2 \bar{\mu} \bar{\epsilon} + i \lambda^2 \omega \bar{\mu} \bar{\sigma} \equiv \bar{e} + i \bar{s} \tag{18a}$$

$$\bar{K} = (l^2 - \bar{k}^2)^{1/2} = 2^{-1/2} \left[\left\{ (l^2 - \bar{e})^2 + \bar{s}^2 \right\}^{1/2} + \left| l^2 - \bar{e} \right| \right]^{1/2} - i 2^{-1/2} \left[\left\{ (l^2 - \bar{e})^2 + \bar{s}^2 \right\}^{1/2} - \left| l^2 - \bar{e}^2 \right| \right]^{1/2}. \tag{18b}$$

In the above four regions, respectively, solutions for E will be sought in the form

$$E_i = \int_0^\infty J_1(l\rho) Z_i(l, z) dl, \qquad i = 1, 2, 3, 4 \tag{19}$$

where the Z_i are defined by eqs. (14), (16), (17) and (18). Assuming the uniform convergence* of the integral in eq. (19), the solutions for the components of the magnetic intensity are, on the basis of eqs. (19) and (2)—

$$H_\rho = - i \lambda^{-1} \omega^{-1} \mu^{-1} \int_0^\infty J_1(l\rho) \dot{Z}_i(l, z) dl \tag{20}$$

$$H_z = i \lambda^{-1} \omega^{-1} \mu^{-1} \int_0^\infty J_0(l\rho) Z_i(l, z) l dl. \tag{21}$$

The "dot" notation, $\dot{Z}_i$, will be used henceforth to indicate differentiation with respect to z.

BOUNDARY CONDITIONS

At each of these three surfaces, $z = 0$, $z = h$, $z = H$, two† independent boundary conditions must be satisfied; namely, (1) the electric vector E is continuous, and

* The uniform convergence of essentially the same integral was established in reference (2) p. 414.

† The quantity μH_z is also continuous everywhere, but this requirement is automatically fulfilled by the corresponding requirement with respect to E.

(2) the component H_ρ is continuous, except at the source, where H_ρ has a discontinuity equal to the surface-current density, $m(\rho)$. The continuity of E at $z=0$ requires that

$$\int_0^\infty J_1(l\rho)(A_2 - A_1)dl = 0, \qquad z = 0 \tag{22}$$

namely—

$$A_2 - A_1 = 0 \tag{23}$$

since eq. (22) must be satisfied independently of ρ. Using eqs. (20), (14), and (16), the condition with respect to H_ρ at the source is—

$$-i\lambda^{-1}\omega^{-1}\mu_0^{-1}\int_0^\infty (B_2 - A_1)(l^2 - k_0^2)^{1/2}J_1(l\rho)dl = m(\rho), \quad 0 < \rho < a \tag{24}$$
$$= 0, \quad \rho > a$$

where "a" is the radius of the source disk.

Two conditions corresponding to eqs. (22) and (24) may be written for each of the remaining two boundaries $z=h$, $z=H$. However, in the two equations for $z=H$, there appear *five* additional unknown functions—namely $Z_1(l, H)$, $Z_2(l, H)$, their derivatives with respect to z, and the unknown coefficient, $A_4(l)$. These two boundary conditions, therefore, can furnish no assistance in the present problem. At the boundary $z=h$, on the contrary, *four* equations of condition may be written—the two conditions of continuity for the electromagnetic field, corresponding to eqs. (22) and (24), and two additional conditions which will be developed presently, arising from the observed values of H_ρ and H_z at the surface. The two continuity conditions are—

$$Z_2(l, h) - Z_3(l, h) = 0 \tag{25}$$

$$\mu_1\dot{Z}_2(l, h) - \mu_2\dot{Z}_3(l, h) = 0 \tag{26}$$

where μ_1 is the value of the permeability just below the ground's surface.

The two additional conditions may be expressed by the inversion of eqs. (20) and (21) by use of the Fourier-Bessel inversion theorem (Watson, §14.4). Thus—

$$\dot{Z}_i(l, z) = i\lambda\omega\mu l\int_0^\infty J_1(l\rho)H_\rho(\rho, z)\rho d\rho \tag{27}$$

$$Z_i(l, z) = -i\lambda\omega\mu\int_0^\infty J_0(l\rho)H_z(\rho, z)\rho d\rho, \qquad i = 1, 2, 3, 4. \tag{28}$$

At the surface, $H_\rho(\rho, h)$ and $H_z(\rho, h)$ are observable, and accordingly $\dot{Z}_i(l, h)$ and $Z_i(l, h)$, $i=2, 3$, are regarded as known. When $m(\rho)$ satisfies appropriate conditions, eq. (24) may also be inverted to yield an expression for B_2-A_1 in terms of

$m(\rho)$. In particular, it is convenient* to choose $m(\rho)$ as follows—

$$\begin{aligned} m(\rho) &= \rho, && 0 \leqq \rho < a \\ &= 1/2, && \rho = a \\ &= 0, && \rho > a. \end{aligned} \tag{29}$$

For this case, comparison of eq. (24) with the known discontinuous integral

$$\begin{aligned} a^2 \int_0^\infty J_2(al)J_1(\rho l)dl &= \rho, && 0 \leqq \rho < a \\ &= 1/2, && \rho = a \\ &= 0, && \rho > a \end{aligned} \tag{30}$$

leads to the relation—

$$B_2 - A_1 = i\lambda\omega\mu_0 a^2(l^2 - k_0^2)^{-1/2}J_2(al) \equiv F_1(l, a, k^2) \tag{31}$$

where the right member, abbreviated by F_1, is known.

In summary, after incorporating the identity $A_1 = A_2$, there remain *three* conditions between the two unknown coefficients A_2 and B_2. Thus—

$$A_2 - B_2 = -F_1 \tag{31a}$$

$$A_2 \cosh K_0 h + B_2 \sinh K_0 h = Z_3(l, h) \tag{25a}$$

$$A_2 \sinh K_0 h + B_2 \cosh K_0 h = \mu_0\mu_1^{-1}K_0^{-1}\dot{Z}_3(l, h) \tag{26a}$$

where the right members are all known. The solutions of the pair (25a) and (26a) substituted in (31a), lead to the following relationship between Z_3 and $\dot{Z}_3$—

* From the results for this somewhat artificial choice of source it is easy to deduce the corresponding results for the practicable case of a single circular current loop. The source radius "a" enters the problem only in the factor $a^2J_2(al)$, as in eq. (31). Thus if the function $\psi_i(z, l)$ is defined by the condition

$$a^2J_2(al)\psi_i(z, l) \equiv Z_i(z, l)$$

eq. (19) may be written

$$E_i = a^2 \int_0^\infty J_2(al)J_1(\rho l)\psi_i(z, l)dl.$$

The field E_{0i} for a source consisting of current density "a" in an annulus of radius "a" and width Δa (namely total current $a\Delta a \equiv c$) clearly is—

$$E_{0i} = \frac{\partial E_i}{\partial a}\Delta a = ac \int_0^\infty J_1(al)J_1(\rho l)\psi_i(z, l)ldl.$$

Since $J_2(al) \doteq \frac{1}{8}a^2l^2$ and $J_1(al) \doteq \frac{1}{2}al$ when al is small, the following simple relation then exists between E_{0i} and E_i

$$E_{0i} = 4E_i\frac{\Delta a}{a} = \frac{1}{2}a^2c \int_0^\infty J_1(\rho l)\psi_i(z, l)l^2dl.$$

In the case of a coil of radius "a" in a homogeneous medium of propagation constant $k^2 = e + is$, the components H_ρ and H_z then are—

$$\mu_0\mu_1^{-1}K_0^{-1}\dot{Z}_3 = Z_3 + F_1\{\sinh K_0h + \cosh K_0h\}^{-1} \tag{32}$$

which, incidentally, is general in the sense that it is independent of the electrical properties of the ground. Clearly a relationship of the type (32) also holds at all levels $z<h$. Namely—

$$K_0^{-1}\dot{Z}_1(z) = Z_1(z), \quad z<0 \tag{32a}$$

and

$$K_0^{-1}\dot{Z}_2(z) = Z_2(z) + F_1\{\sinh K_0z + \cosh K_0z\}, \quad 0<z<h. \tag{32b}$$

These relationships, in the light of eqs. (20), (21), (27) and (28) show that the vertical and horizontal components of the magnetic intensity are dependent. On any plane $z_i \leqq h$ knowledge of $H_\rho(\rho, z_i)$ suffices to determine $H_z(\rho, z_i)$ and vice-versa. Thus, there is in reality only one independent observable function, namely $H_z(\rho, z_i)$ or $H_\rho(\rho, z_i)$.

$$H_\rho = \frac{ac}{2}\int_0^\infty J_1(la)J_1(l\rho)e^{\mp Kz}ldl$$

$$H_z = \frac{ac}{2}\int_0^\infty J_1(la)J_0(l\rho)e^{\mp Kz}K^{-1}l^2dl$$

where

$$K \equiv (l^2 - k^2)^{1/2} \qquad l > k$$
$$\equiv i(k^2 - l^2)^{1/2} \qquad l < k$$

and the upper sign applies for $z>0$, and vice-versa. By use of the Sommerfeld integral

$$r^{-1}e^{-ikr} = \int_0^\infty J_0(l\rho)e^{-Kz}K^{-1}ldl$$

and its successive derivatives with respect to a, ρ, or z it is easy to obtain from the above expressions for H_ρ and H_z the classical formulae for (a) the field H_z on the axis of the coil, and (b) the expressions for the field components H_ρ and H_z at distances $r=(z^2+\rho^2)^{1/2}$ which are large compared to a. These formulae are—

(a)
$$H_z(0, z) = \frac{a^2c}{2R^3}(1 + ikR)e^{i(\omega t-kR)},$$

where $R\equiv(a^2+z^2)^{1/2}$.

(b)
$$H_\rho(\rho, z) = \frac{3a^2c}{4}(r^{-3} + ikr^{-2})\rho zr^{-2}e^{i(\omega t-kr)}$$

$$H_z(\rho, z) = \frac{a^2c}{4}[r^{-3}(3z^2r^{-2} - 1) + ikr^{-2}(3z^2r^{-2} - 1) + k^2r^{-1}(1 - z^2r^{-2})]e^{i(\omega t-kr)}.$$

THE "KERNEL" FUNCTION

The "kernel" function,* $K_3(l, h)$, having real and imaginary parts K_3' and K_3'', is defined as follows—

$$K_3(l, h) \equiv -\frac{\dot{Z}_3(l, h)}{lZ_3(l, h)} = K_3'(l, h) + iK_3''(l, h). \tag{33}$$

By virtue of eqs. (27) and (28), or from either of these together with eq. (32), it is apparent that the kernel is determined by the field observations, and vice-versa. More specifically, let

$$\begin{aligned} Z_3 &= Z_3' + iZ_3'' \\ H_z(\rho, h) &= H_z'(\rho, h) + iH_z''(\rho, h) \end{aligned} \tag{34}$$

and similarly for $H_\rho(\rho, h)$. Also let the functions u_0, v_0, u_1, v_1, be defined in terms of the observable field components as follows—

$$\begin{aligned} u_0 &\equiv \int_0^\infty J_0(l\rho)H_z'(\rho, h)\rho d\rho \\ v_0 &\equiv \int_0^\infty J_0(l\rho)H_z''(\rho, h)\rho d\rho \\ u_1 &\equiv \int_0^\infty J_1(l\rho)H_\rho'(\rho, h)\rho d\rho \\ v_1 &\equiv \int_0^\infty J_1(l\rho)H_\rho''(\rho, h)\rho d\rho. \end{aligned} \tag{35}$$

One then obtains, by use of eqs. (27) and (28)—

$$K' = \frac{u_0u_1 + v_0v_1}{u_0^2 + v_0^2}, \qquad K'' = \frac{u_0v_1 - u_1v_0}{u_0^2 + v_0^2}. \tag{36}$$

Let us write—

$$Z_3(l, z) = R(l, z) \exp\left\{i\int \beta(l, z)dz\right\} \tag{37}$$

where R and β are real. Then

$$K_3(l, z) = -\frac{\dot{R}(l, z)}{lR(l, z)} - i\frac{\beta(l, z)}{l} \equiv K_3' + iK_3''. \tag{38}$$

* The corresponding functions of z, $K_3(l, z)$, $K_2(l, z)$, will also be referred to as "kernel" functions.

By substitution of equation (37) into eq. (13), one obtains—

$$\ddot{R} - \dot{\mu}\mu^{-1}\dot{R} - (l^2 - e + \beta^2)R = 0 \tag{39}$$

$$\dot{\beta} + (2\dot{R}R^{-1} - \dot{\mu}\mu^{-1})\beta = -s(z) \tag{40}$$

If the substitution $u \equiv \dot{R}/R$, $R \neq 0$ be introduced into eq. (39), this becomes a Riccati equation—

$$\dot{u} - \dot{\mu}\mu^{-1}u + u^2 = l^2 + \beta^2(z, l) - e(z, \omega). \tag{41}$$

Within a factor $-l$, the quantities u and β in eqs. (40) and (41) are the real and imaginary components of the kernel. It might be expected from eqs. (35) that these components are functions of h, and also probably of the source radius a and the current distribution $m(\rho)$. However, eqs. (40) and (41) exhibit differential relationships between the kernel components and the properties of materials which stem directly from the field equations (in their present symmetrical form) independently of the boundary conditions, or properties of the source. It will appear later (see eqs. (51) and (52) et seq.) that the asymptotic expansion of the kernel is in fact uniquely determined by the electrical characteristics of the ground; and conversely, from the asymptotic expansion may be determined the functions expressing the variation of the electrical properties with depth. For $z > H$, the solution of eqs. (39) and (40) is, in accordance with eq. (18), $Z_4 \equiv A_4 \exp\left\{-(l^2 - \bar{k}^2)^{1/2}z\right\}$ and the corresponding kernel is

$$K_4 \equiv -\frac{\dot{Z}_4}{lZ_4} = (l^2 - \bar{k}^2)^{1/2}l^{-1} = (1 - \bar{e}l^{-2} - i\bar{s}l^{-2})^{1/2}. \tag{42}$$

For large values of l, the expansions of the real and imaginary parts of K_4 are, respectively—

$$-\frac{\dot{\bar{R}}}{l\bar{R}} = 1 - \frac{1}{2}\bar{e}l^{-2} + \frac{1}{8}(\bar{s}^2 - \bar{e}^2)l^{-4} + \frac{1}{16}(3\bar{s}^2 - \bar{e}^2)\bar{e}l^{-6} \cdots \tag{43}$$

$$\frac{\bar{\beta}}{l} = \frac{\bar{s}}{2}l^{-2} + \frac{1}{4}\bar{s}\bar{e}l^{-4} + \frac{1}{16}(3\bar{e}^2 - \bar{s}^2)\bar{s}l^{-6} \cdots . \tag{44}$$

These results suggest the following asymptotic expansions for the real and imaginary parts, respectively, of the corresponding kernel K_3—

$$-\frac{\dot{R}(l, z)}{lR(l, z)} \sim \sum_{i=0}^{\infty} r_i l^{-i}, \quad \text{with} \quad r_0 = 1.0 \tag{45}$$

and

$$\frac{\beta(l, z)}{l} \sim \frac{1}{2}\sum_{i=1}^{\infty} b_i l^{-i-1} \tag{46}$$

where the unknown coefficients r_i and b_i are real functions of z (and of ω), but *not* functions of l. Each coefficient is analytic in the interval $h \leqq z \leqq H$. When $z=h$, the left members of eqs. (45) and (46) reduce respectively to the known functions $K'(l, h)$ and $-K''(l, h)$. The coefficients r_i and b_i are therefore all to be regarded as known at $z=h$, for any assigned values of λ and ω.

When l is sufficiently large, the series (45) and (46) are absolutely convergent. Let these asymptotic expansions be substituted in eqs. (40) and (41), yielding, for large values of l—

$$-\sum_{i=1}^{\infty}\left(\dot{b}_i/2 - \frac{\dot{\mu}}{2\mu}b_i\right)l^{-i} + b_1 + (b_1r_1 + b_2)l^{-1} + (b_1r_2 + b_2r_1 + b_3)l^{-2} + (b_1r_3 + b_2r_2 + b_3r_1 + b_4)l^{-4} + \cdots = s(z, \omega) \tag{47}$$

$$-\sum_{i=1}^{\infty}\dot{r}_i l^{1-i} + \dot{\mu}/\mu\sum_{i=0}^{\infty} r_i l^{1-i} + 2l^2\{r_1 l^{-1} + (r_2 + r_1^2/2)l^{-2} + (r_3 + r_2r_1)l^{-3} + (r_4 + r_3r_1 + r_2^2/2)l^{-4} + \cdots\} - \tfrac{1}{4}\{b_1^2l^{-2} + 2b_2b_1l^{-3} + (2b_3b_1 + b_2^2)l^{-4} + \cdots\} = -e(z, \omega). \tag{48}$$

Since the right members of these equations are independent of l, being functions of z and ω alone, the coefficients of all powers of l except the null power must vanish. This requirement leads to the following two sets of conditions, relating the first derivatives of the functions b_i and r_i respectively to certain combinations of these functions themselves. Thus—

(a) $b_1 = s(z)$; (b) $\dot{b}_1 = 2b_2$; (c) $\dot{b}_2 = 2(b_1r_2 + b_3)$;

. . . . . .

$$\dot{b}_n = 2\sum_{i=1}^{n-1} b_i r_{n+1-i} + 2b_{n+1} \tag{49}$$

. . . . . .

(a) $r_0 = 1$; (b) $r_1 = -\dot{\mu}/2\mu$; (c) $\dot{r}_1 = 2r_2 - r_1^2 + e(z)$

(d) $\dot{r}_2 = 2r_3$; (e) $\dot{r}_3 = r_2^2 + 2r_4 - b_1^2/4$; (50)

(f) $\dot{r}_4 = 2(r_5 + r_3r_2) - b_1b_2/2$;

(g) $\dot{r}_5 = 2(r_6 + r_4r_2 + r_3^2/2) - \frac{1}{4}(2b_1b_3 + b_2^2)$

(h) $\dot{r}_6 = 2(r_7 + r_5r_2 + r_4r_3) - \frac{1}{2}(b_1b_4 + b_2b_3)$; etc.

. . . . . .

(In eqs. (50c) and (49b) the result $\dot{\mu}/\mu = -2r_1$, from eq. (50b) has been introduced.) The above relations permit the successive evaluation of the derivatives of b_1 and of r_2 of all orders, in terms of the functions b_i and r_i. Thus—

$$\begin{aligned} b_1 &= s(z); \qquad \dot{b}_1 = 2b_2; \qquad \ddot{b}_1 = 2\dot{b}_2 = 4(b_1r_2 + b_3); \\ \dddot{b}_1 &= 4(\dot{b}_1r_2 + \dot{r}_2b_1 + \dot{b}_3) = 16(b_2r_2 + b_1r_3 + b_4/2); \\ b_1^{IV} &= 16[3b_1r_2^2 + 3b_3r_2 + 5b_2r_3 + 3b_1r_4 - b_1^3/4 + b_5] \\ &\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \end{aligned} \tag{51}$$

and—

$$\begin{aligned} r_2 &= \frac{1}{2}(\dot{r}_1 + r_1^2 - e(z)) \\ \dot{r}_2 &= 2r_3; \qquad \ddot{r}_2 = 2(r_2^2 + 2r_4 - b_1^2/4) \\ \dddot{r}_2 &= 8(3r_2r_3 + 2r_5 - b_1b_2) \\ r_2^{IV} &= 8\left(4r_6 + 8r_3^2 + 3r_2^2 + 10r_4r_2 - \frac{11}{4}b_1^2r_2 - 3b_1b_3 - \frac{5}{2}b_2^2\right) \\ &\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \end{aligned} \tag{52}$$

Since b_1, r_2, and the right members of the remaining equations in the sets (51) and (52) are all known at the surface $z=h$, the conductivity function $b_1=s(z)\equiv\lambda^2\omega\mu\sigma$ and the function r_2 may each be expanded at $z=h$ in a Taylor's series with known coefficients. It is to be noted that the determination of the coefficients in the above expansions does not require explicit knowledge of any of the three electrical properties of material.

Conversely, if it be supposed that the functions $s(z)$, and $r_2(z)$ and all their derivatives are known, eqs. (51) and (52) then constitute a system for the successive determination of the functions b_i and r_i in terms of the derivatives of $b_1=s(z)$, and $r_2(z)$. Thus the asymptotic expansion of the kernel is fixed by the electrical properties of material alone.

EQUIVALENCE OF SOLUTIONS FOR THE MAGNETOSTATIC AND ELECTRIC POTENTIAL PROBLEMS

Of the three terms $\dot{\mu}/\mu$, e, and s involving properties of material, only the first is independent of the frequency and of the geometric scale factor λ. When the products $\omega^2\lambda^2$ and $\omega\lambda^2$ are sufficiently small, the functions e and s vanish, and the permeability becomes the overriding property of material. Furthermore, when $s=0$, all the coefficients b_i in the asymptotic series for the imaginary part of the kernel also vanish. In this case the set (50) (by successive differentiation of eq. (50c), with substitution in the resultant equations of the values of $\dot{r}_i$ listed in eqs. (50)) yields the following expressions for r_1 and its successive derivatives—

$$
\begin{aligned}
r_1 &= -\dot{\mu}/2\mu; \qquad \dot{r}_1 = -r_1^2 + 2r_2; \\
\ddot{r}_1 &= 2r_1^3 - 4r_1r_2 + 4r_3 \\
\dddot{r}_1 &= 16r_1^2r_2 - 6r_1^4 - 8r_1r_3 - 4r_2^2 + 8r_4 \\
&\cdots\cdots\cdots

for r_2, namely,

$$e(z) = -2r_2. \tag{55}$$

When the permeability is variable, the dielectric function, which is linear in ω^2, may be determined by the aid of observations at two different frequencies, $\omega_1/2\pi$ and $\omega_2/2\pi$. For convenience, it will be assumed that $\omega_2^2 = 2\omega_1^2$. Since the functions r_1 and $\dot{r}_1$ are determined by the permeability alone, independently of the frequency, these quantities may be eliminated in eq. (50c) by forming this equation for two frequencies and differencing—one thus obtains (when $\omega_2^2 = 2\omega_1^2$)—

$$e(z, \omega) = 2\{r_2(z, \omega_1) - r_2(z, \omega_2)\} \tag{56}$$

where formulae for the coefficients in the Taylor's series for $r_2(z, \omega)$ have already been found.

EVALUATION OF THE PERMEABILITY, GENERAL CASE

The solution for the permeability for the magnetostatic case was obtained in a previous paragraph. Because of the well known advantages in respect to sensitivity obtained by the use of alternating current techniques, it is desirable to deduce a formula for μ valid in the general case. Assuming that $e(z, \omega)$ has been found in accordance with eq. (56), one may use eq. (50c) as the basis for determining the successive derivatives of $r_1(z)$. One thus obtains—

$$\begin{aligned}
\dot{r}_1(\omega_1) &= 4r_2(\omega_1) - 2r_2(\omega_2) - r_1^2(\omega_1) \\
\ddot{r}_1(\omega_1) &= 4\dot{r}_2(\omega_1) - 2\dot{r}_2(\omega_2) - 2r_1\dot{r}_1 \\
\dddot{r}_1(\omega_1) &= 4\ddot{r}_2(\omega_1) - 2\ddot{r}_2(\omega_2) - 2\dot{r}_1^2 - 2r_1\ddot{r}_1, \quad \text{etc.} \\
&\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots
\end{aligned} \tag{57}$$

Here the derivatives of r_2 of all orders are known (eq. 52); and the derivatives of r_1 occurring in the right members may always be expressed in terms of previous members of the set (57) which contain no derivative terms. Thus one obtains a Taylor's series for r_1 whose coefficients are known at the surface. This enables the computation of the permeability in accordance with eq. (54). Two points concerning the formula for the permeability may be noted. (1) Unlike the solutions for the other two electrical properties, the Taylor series, or rather its first integral, appears as the *logarithm* of the permeability. This type of result is to be expected, since it is the *ratio* of permeabilities that has significance in determining the distribution of the magnetic induction. Conversely, as is well known, the *absolute* values of the conductivity and dielectric constant have significance in electrodynamic problems. (2) Secondly, in the solutions both for the permeability and for the dielectric function, the quantities r_i from the *real* part of the kernel have the predominant role.

AN ALGEBRAIC CHECK

A partial algebraic check for the expansions of $s(z)$, $e(z)$, and $\mu(z)$ derived above is afforded by comparison with known results for the case of a uniform half-space. For this case, the asymptotic series for the real and imaginary parts of the kernel have been written in eqs. (43) and (44) respectively.

Upon substituting the particular values for r_i and b_i found in these expansions into the general formulae for the successive derivatives of $b_1(z)=s(z)$ listed in eq. (51), it is seen that all these derivatives, except the zero order, vanish; whereas the latter yields the correct constant value, $s=\bar{s}$, for the conductivity function. For example, the fourth derivative becomes—

$$s^{IV} = b_1^{IV} = 16[3b_1r_2^2 + 3b_3r_2 + 5b_2r_3 + 3b_1r_4 - b_1^3/4 + b_5]$$

$$= 16\left[\frac{3}{4}\bar{s}\bar{e}^2 + 3\frac{\bar{s}\bar{e}}{2}\left(-\frac{\bar{e}}{2}\right) + \frac{3\bar{s}}{8}(\bar{s}^2 - \bar{e}^2) - \bar{s}^3/4 + \frac{1}{8}(3\bar{e}^2 - \bar{s}^2)\bar{s}\right] = 0. \quad (58)$$

A similar test may be made with respect to the dielectric function. When the special values of r_i and b_i in eqs. (43) and (44) are introduced into the formulae (eq. 52) for the derivatives of $r_2(z)$, it is again found that these derivatives all vanish, and the known result, $e(z)=\bar{e}$, is obtained. For example, the rather long formula for r_2^{IV} in eq. (52) reduces to—

$$r_2^{IV} = 8\left[\frac{\bar{e}}{4}(3\bar{s}^2 - \bar{e}^2) - \frac{3}{8}\bar{e}^3 - \frac{5}{8}\bar{e}(\bar{s}^2 - \bar{e}^2) + \frac{11}{8}\bar{s}^2\bar{e} - \frac{3}{2}\bar{s}^2\bar{e}\right] = 0. \quad (59)$$

Finally, in view of eq. (50b), it is clear that the result $r_1=0$ in eq. (43) also satisfies the requirement that the permeability be constant. The value of this constant is not revealed, but from the physical point of view it may be regarded as known from surface samples.

SPECIAL CASES

A. Conductivity Predominates

It has been shown that in theory the conductivity function may always be determined from observations at a single frequency. (In practice a frequency, or several frequencies, suitable to the geometric scale and to the resistivity, i.e. to the "electrical scale" of the problem, would of course be chosen.) On the other hand, measurements at two different frequencies are in general required for determining the permeability and dielectric constant. In case either $e(z)$ or $\mu(z)$ is a known function, then it is clear from eq. (50), and from considerations previously developed, that the other function may be found from observations made at a single frequency. However, if both the permeability and dielectric constant are known, the problem is over-determined, and the real and imaginary parts of

the kernel are then dependent. For example, let the dielectric function be vanishingly small in comparison with the conductivity terms, and let the permeability be any constant. Then the set (50) furnishes expressions for the coefficients r_i in terms of b_i, and vice versa. Thus—

$$\begin{aligned} &r_0 = 1; \quad r_1 = r_2 = r_3 = 0; \quad r_4 = b_1^2/8; \quad r_5 = b_1 b_2/2 \\ &r_6 = \left(\frac{3}{4} b_1 b_3 + \frac{5}{8} b_2^2\right); \quad r_7 = b_1 b_4 + \frac{9}{2} b_2 b_3 \\ &r_8 = \frac{15}{128} b_1^4 + \frac{5}{4} b_1 b_5 + \frac{7}{2} b_2 b_4 + \frac{19}{8} b_3^2 \\ &\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \end{aligned} \tag{60}$$

Conversely—

$$\begin{aligned} &b_1 = 2(2r_4)^{1/2}; \quad b_2 = r_5(2r_4)^{-1/2}; \\ &b_3 = \frac{2}{3}(2r_4)^{-1/2}\left(r_6 - \frac{5}{16} r_5^2 r_4^{-1}\right) \\ &b_4 = r_7 - \frac{3}{2} r_5 r_4^{-1}\left(r_6 - \frac{5}{16} r_5^2 r_4^{-1}\right) \\ &\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \end{aligned} \tag{61}$$

The expansion for the conductivity function in this case takes the following simple form—

$$\begin{aligned} s(z) = {} & b_1 + 2b_2\eta + 2b_3\eta^2 + \frac{4}{3} b_4\eta^3 \\ & + (b_1^3/12 + 2/3 b_5)\eta^4 + \frac{4}{15}(b_2 b_1^2 + b_6)\eta^5 + \cdots \end{aligned} \tag{62}$$

where $\eta \equiv z - h$. In these coefficients, all quantities r_i have been eliminated by use of the relations (60). An alternative expansion, in terms of coefficients determined by the real part of the kernel only, has a more intricate form.

B. Dielectric Function Predominates

Conversely, when the conductivity is very small and the frequency high, the dielectric function may predominate. (For example, when $\epsilon \geqq 20\epsilon_0$, $\sigma^{-1} \geqq 10^5$ ohm meter, $f \geqq 1$ megacycle, then the ratio $e/s \geqq 111.2$) If in such cases the conductivity is set zero, then all the coefficients b_i in the expansion of the imaginary part of the kernel necessarily vanish; accordingly, the Taylor's expansion for $e(z)$ (see eq. 52) will involve only the coefficients r_i from the real part of the kernel, and no alternative expansion exists. Thus—

$$e(z) = -2\left[r_2 + 2r_3\eta + (r_2^2 + 2r_4)\eta^2 + \frac{4}{3}(3r_2r_3 + 2r_5)\eta^3 + \frac{1}{3}(4r_6 + 8r_3^2 + 3r_2^2 + 10r_4r_2)\eta^4 + \cdots\right]. \quad (63)$$

In the general case when neither the conductivity, the dielectric constant, nor the permeability dominates, it will be noted that there always exists, on the one hand, an association of the conductivity with the imaginary part of the kernel; and on the other, a similar association of the dielectric constant and the permeability with the real part. Namely, the first two coefficients (eq. 51) in the solution for the conductivity are, respectively, the first coefficient, and twice the second, in the expansion of the imaginary part of the kernel; similarly, the first two coefficients in the solution of the dielectric function (eqs. 56 and 52), are the second coefficient, and twice the third, respectively, in the expansion of the real part of the kernel. Likewise, the Taylor's expansion for the logarithm of the permeability contains in its first three coefficients (see eqs. 57 and 52) only quantities r_i from the first three terms of the real part of the kernel series. Thus a gross separation of the conductivity, dielectric constant, and permeability may be affected by determining only the first two terms in the asymptotic expansion of K_3' and the first three in the expansion of K_3''. Since the frequency enters the permeability function as the null power, the conductivity as the first power, and the dielectric function as the square, it is obvious without analysis that observations at several suitable frequencies are desirable in effecting the separation of these three functions.

SUMMARY

Solutions for the unknown variation of the dielectric function and conductivity function with depth have been obtained in the form of Taylor's series, whose coefficients may be deduced from the measurement of the horizontal or vertical components of the magnetic intensity at the surface. In the case of the permeability the logarithm of this function is expressed as the first integral of a Taylor's series. A partial check upon the form of these expansions is afforded by comparison with results for a known special case. It is shown that the horizontal and vertical components of the magnetic intensity are dependent; and an equation of connection, whose form is independent of the electrical characteristics of the ground, is obtained. When the frequency is small or zero, the magnetostatic problem is formally equivalent to a previously solved problem in direct current flow.

In general, the determination of the permeability (unless the frequency is small or zero) and of the dielectric function requires observations at two frequencies. However, the conductivity function may be determined by observations at a single frequency. The association of the conductivity function with the imaginary part of the kernel; and the association of the dielectric and permeabil-

ity functions with the real part, are noted. When the conductivity is the overriding property, the first half dozen coefficients in its Taylor's expansion have a simple form and are simply related to those in the asymptotic expansion of the imaginary part of the kernel.

The practicability of the present analytical procedures, which lead to power series solutions for the electrical properties, obviously depends strongly upon the complexity of the variations in these properties. If these are of simple type, a few terms in the power series may suffice to provide a satisfactory description of the average behavior of the functions for a limited range of depth. If the functions are oscillatory, of the nature of the curve for μ in Figure 1, the method is undoubtedly essentially useless, for then an impracticably large number of terms would in general be needed, whose determination would demand an impossible precision of field observations. All the so-called "flux" methods of geophysical prospecting are inherently averaging processes, which yield a strongly "smoothed-over" version of the true physical variations in the crust. Thus it scarcely requires mention that a large gap exists between the practical possibilities of deducing the physical or geological structure and the present mathematical analysis, in which certain tacit assumptions, such as the assumptions of the needed precision of measurement and of the necessary degree of structural symmetry, are implied.

BIBLIOGRAPHY

Langer, R. E., *Bulletin of American Mathematical Society*, 39, (1933), 184.
Slichter, L. B., *Physics*, vol. 4 (Dec. 1933), 411–418.
———, *Physics*, vol. 4 (Sept. 1933), 307–322.
Mason and Weaver, *The Electromagnetic Field*, University of Chicago Press, 1929.
Stratton, *Electromagnetic Theory*, McGraw-Hill (1941).
Watson, G. N., *Bessel Functions*, Cambridge University Press, 2nd Edition.

A STUDY OF THE INFLUENCE OF BACKGROUND NOISE ON REFLECTION PICKING*

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ABSTRACT

To evaluate the ability of interpretational personnel to pick reflected energy in presence of variable amount of noise, recordings were made using random ground unrest and superimposing thereupon a controllable amount of synthetic reflection energy. The description of apparatus used and the results of picking of such records are given.

INTRODUCTION

A brief study was undertaken in order to evaluate the ability of interpretational personnel to pick reflected energy in the presence of variable amounts of background noise. This study was made under laboratory conditions wherein the reflections were produced synthetically in a random but known time sequence, and noise of random character was superimposed thereupon. The ratio of signal to noise was controlled. The records obtained were picked by personnel who have had a considerable amount of experience in interpreting standard seismic records. The times of reflections picked by visual inspection were compared to the times of synthetic reflections introduced into the recording.

PROCEDURE

The functional diagram of the experimental setup is shown in Figure 1. While the actual experiment employed ten individual channels, only six are shown for the sake of simplicity. Referring to Figure 1, each seismic amplifier channel was fed by a separate geophone. These geophones were planted at widely scattered locations around the Laboratory building in order to achieve the effect of random ground unrest. Considerable effort was made to locate planting sites at which the ground unrest was of approximately the same frequency content. A train of synthetic reflection pulses was introduced into the system in unison on all traces (corresponding to zero moveout). This was achieved by triggering a relaxation oscillator from a photoelectric transient generator which produced a train of pulses having a random time distribution. A tuned amplifier shaped the pulse produced by the relaxation oscillator in such a way as to approximate a typical seismic reflection pulse. The synthetic pulse thus generated was fed simultaneously into a set of isolation amplifiers, the output of which was mixed with

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the individual outputs of the seismic amplifiers fed by the geophones. The combined outputs were recorded on a standard recording oscillograph. In addition to the 10-trace recording of the combined signal and noise, an additional trace was recorded which reproduced the synthetic pulse produced by the relaxation oscillator and tuned amplifier. This trace was later used for comparison purposes. A calibrated attenuator was introduced between the tuned amplifier and the isola-

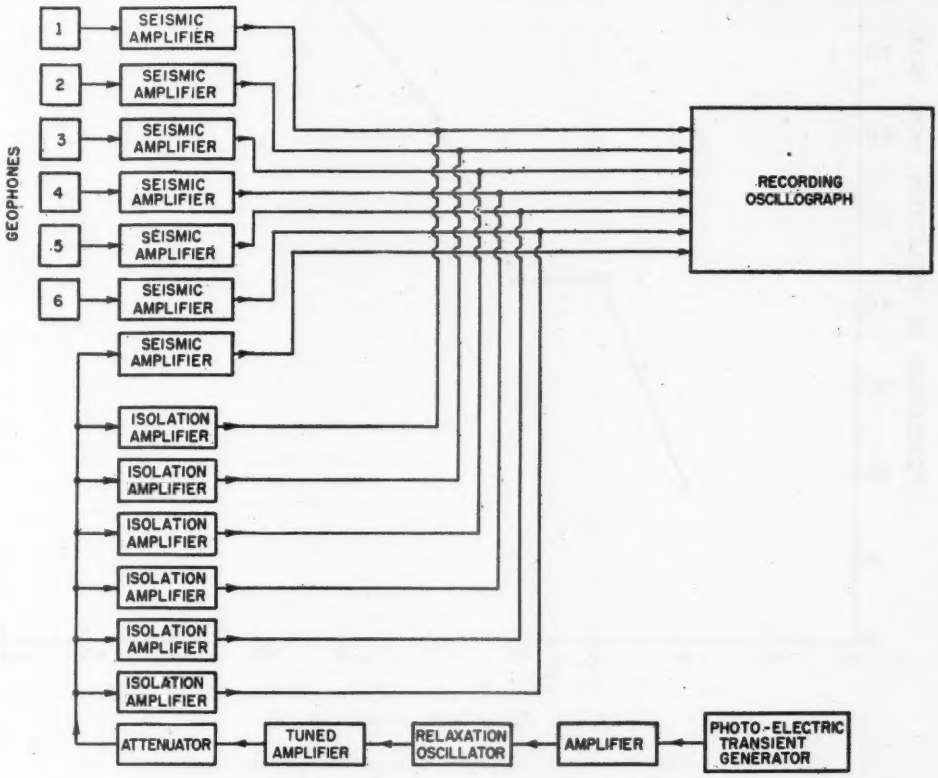

FIG. 1. Experimental setup for producing synthetic reflections and for controlling the ratio of reflection signal to random background noise.

tion amplifiers by means of which the ratio of the amplitude of the synthetic reflections to the random signal generated by the geophones could be varied at will. One set of records was taken for signal-to-noise ratios of $+6$, 0, and -6 db. A second set of records was taken for signal-to-noise ratios of $+6$, 0, -2, -4, and -6 db. In all tests, the noise level was maintained at a substantially constant value for all signal-to-noise ratios except the $+6$ db case. For this case the reflection signal was maintained at the same level as for the 0 db case, but the noise was decreased by 6 db. This procedure was necessary to prevent overdriving of the various components in the system.

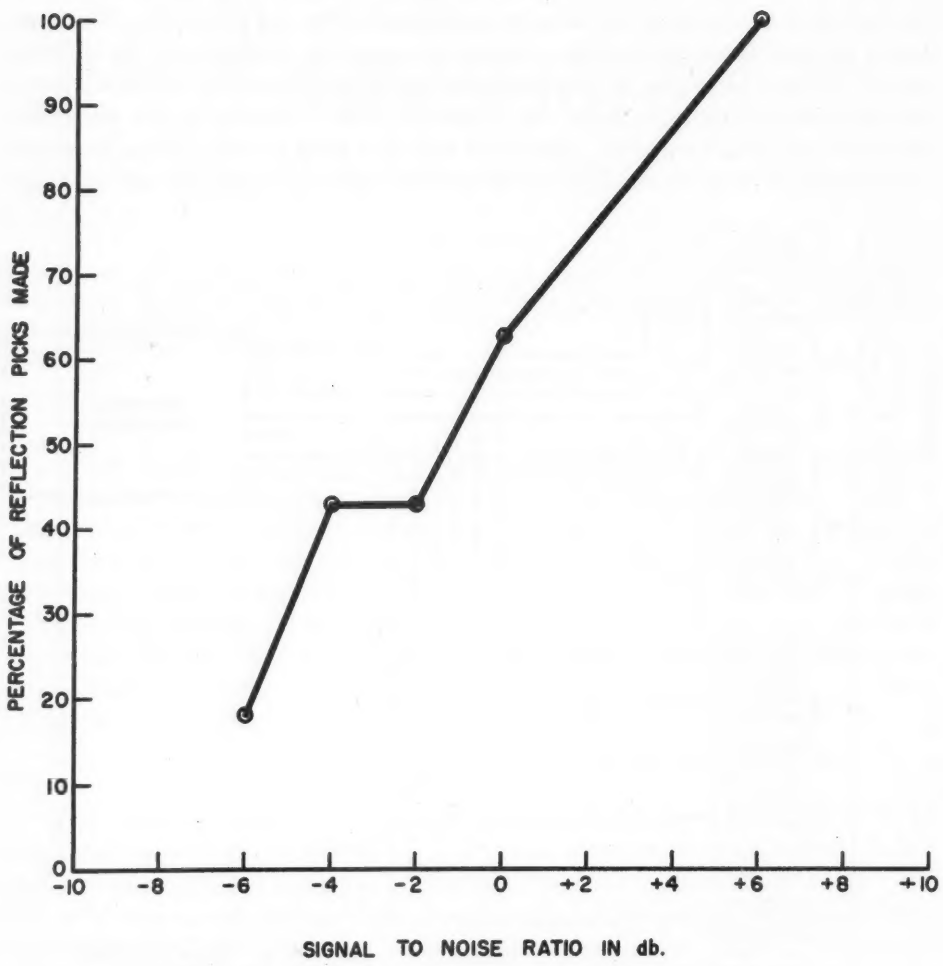

FIG. 2. Per cent of "correct picks" by three independent analyses of one record for each given signal-to-noise ratio.

A portion of a typical synthetic record so obtained is shown in Figure 3. The ratio of signal to noise in this case was adjusted to 0 db. The bottom trace represents the synthetic reflection fed to all traces in unison.

Having obtained a number of synthetic records using the setup described above, the bottom trace representing the synthetic reflection without the background noise was cut off in such a way as to permit later comparison of the cut-off portion with the rest of the record.

RESULTS

The first set of records was analyzed by one interpreter. The results are shown in Table 1. The second set of records was analyzed independently by three dif-

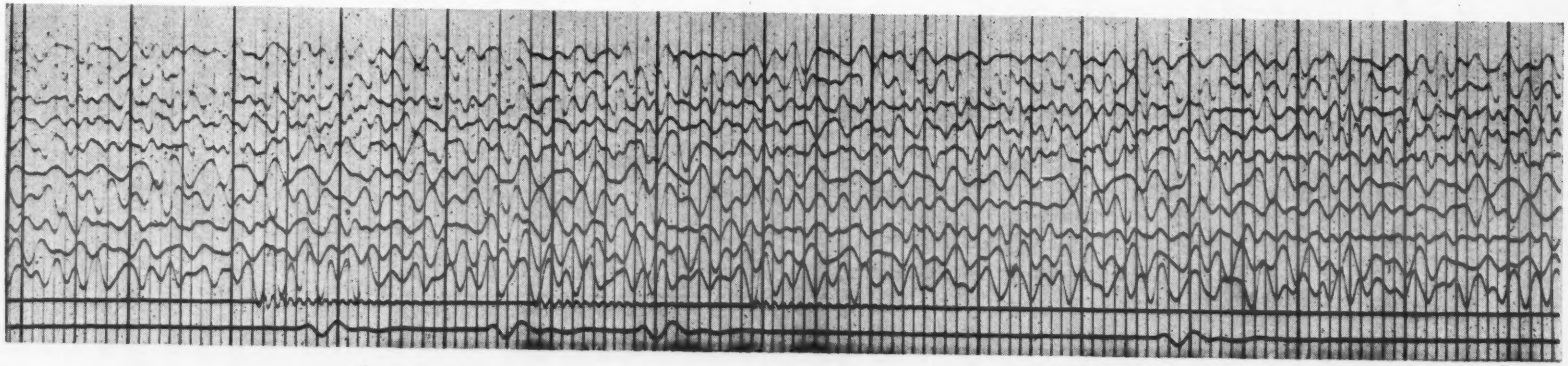

FIG. 3. Synthetic record of random noise and superimposed signal. Signal-to-noise ratio 0 db.

ferent interpreters whose individual skills furnish a representative cross-section of a large group. A tabulation of the average results is shown in Table 2. The per cent of "correct picks" to synthetic reflections is shown in Figure 2 using the data from Table 2.

TABLE 1. SUMMARY OF PICKS BY ONE INTERPRETER ON ONE RECORD FOR EACH GIVEN SIGNAL-TO-NOISE RATIO

Signal to Noise	Good Reflections			Fair Reflections			Poor Reflections			Very Poor Reflections			Record Total				
	No. Picked	No. Correct	No. Extraneous	No. Picked	No. Correct	No. Extraneous	No. Picked	No. Correct	No. Extraneous	No. Picked	No. Correct	No. Extraneous	No. Synthetic Pulses	No. Picked	No. Correct	No. Extraneous	No. Omitted
+6 db	9	9	0	0	0	0	0	0	0	0	0	0	9	9	9	0	0
0 db	0	0	0	4	3	1	4	1	3	6	2	4	9	14	6	8	3
−6 db	0	0	0	1	0	1	4	2	2	9	6	3	11	14	6	6	3

TABLE 2. SUMMARY OF AVERAGE NUMBER OF PICKS FROM THREE INDEPENDENT ANALYSES OF ONE RECORD FOR EACH GIVEN SIGNAL-TO-NOISE RATIO

Signal to Noise	Good Reflections			Fair Reflections			Poor Reflections			Very Poor Reflections			Record Total				
	No. Picked	No. Correct	No. Extraneous	No. Picked	No. Correct	No. Extraneous	No. Picked	No. Correct	No. Extraneous	No. Picked	No. Correct	No. Extraneous	No. Synthetic Pulses	No. Picked	No. Correct	No. Extraneous	No. Omitted
+6 db	0	0	0	3	3	0	3.0	2.7	0.3	3.7	1.3	2.3	7	9.7	7.0	2.7	0.0
0 db	0	0	0	0.7	0.7	0	2.3	2.0	0.3	3.0	2.3	0.7	8	6.0	5.0	1.0	3.0
−2 db	0	0	0	0	0	0	2.0	1.3	0.7	3.0	1.7	1.3	7	5.0	3.0	2.0	4.0
−4 db	0	0	0	0	0	0	0.3	0.0	0.3	1.7	1.3	0.3	3	2.0	1.3	0.7	1.7
−6 db	0	0	0	0	0	0	0.3	0.3	0.0	2.0	1.0	1.0	7	2.3	1.3	1.0	5.7

DISCUSSION

The data clearly indicate that with a signal-to-noise ratio of 0 db or higher the results were very satisfactory, especially since the "very poor" data would be given little weight in the presence of better quality data. At lower signal-to-noise ratios there is a preponderance of "very poor" data and the percentage of extraneous picks increases. At −6 db the number of extraneous and correct picks are about equal so that mapping would be out of the question.

It can be argued that in many respects the experiments did not simulate field conditions. The absence of normal moveout is minor. The absence of weathering jumps tended to increase the ease of picking. No statistical analysis of the noise was made to show its degree of randomness. We feel certain that non-randomness did not extend over more than a few traces at a time, if it was present at all. Since our field recordings are usually replete with this type of non random noise, any tendency in this direction on the experimental records would tend to more nearly simulate field conditions.

One important departure from the usual conditions is the absence of simulated continuous profiling. Continuous profiling would eliminate most of the extraneous picks; being random they would only rarely duplicate in time and pattern on two interlocking spreads. On this basis, the per cent of reflections which can be picked with a given signal-to-noise ratio (fig. 2) becomes important. We see that even for a -6 db ratio a reasonable percentage of reflections can be picked. However, the fraction that can be picked on both of two interlocking profiles would be quite small on a chance basis for a -6 db ratio.

CONCLUSIONS

Within the limitations of the scope of this work and data collected, it is shown that in general the number of correct picks is inversely related to the magnitude of signal-to-noise ratio of seismic signals. On a multi-trace record visual recognition of reflected energy is possible for signal-to-noise ratio as low as -2 db to -6 db. With decreased magnitude of this ratio the percentage of spurious picks increases. The number of such spurious picks would decrease for cases of interlocking continuous profiles.

STUDIES IN NON-STRUCTURAL PETROLEUM PROSPECTING*

I. A NON-STRUCTURAL WORKING HYPOTHESIS FOR PETROLEUM PROSPECTING

E. E. ROSAIRE†

ABSTRACT

A non-structural (i.e., more general than structural) working hypothesis, with a potential usefulness greater than that of the currently accepted geophysical structural working hypothesis, is proposed for petroleum prospecting. This non-structural working hypothesis postulates that an observable anomaly, with potential significance in petroleum prospecting, may originate not only in lithologic structure (the significant structural anomaly), but also in stratigraphic variations in (primary) lithology associated with the presence of petroleum accumulation (the significant stratigraphic anomaly). Thereby, a gradation in types of significant anomalies is anticipated, from the significant structural to the significant stratigraphic anomaly, depending upon the relative magnitudes of structural and stratigraphic effects. Two sub-hypotheses are formulated, the special structural and the special stratigraphic, which are applicable, respectively, to the resolution of the significant structural and the significant stratigraphic anomalies.

An examination of the corollaries from the hypotheses at issue (the currently accepted geophysical structural and the proposed non-structural) indicates that one critical test depends upon the identification of four unique (i.e., unfamiliar) characteristics postulated for the near-surface significant stratigraphic anomaly; these are magnitude at a shallow depth of survey, configuration, orientation of maximum expression, and change in configuration with depth of survey.

INTRODUCTION

"Non-structural" petroleum prospecting is to be interpreted as "more general than structural" petroleum prospecting, not as "anti-structural" petroleum propecting. In his choice of a designation with advantage in terseness but disadvantage in description, the writer has adopted a nomenclature accepted in other fields of investigation. Thus, in the field of geometry, physics and logic, the procedure has been as follows.

A hypothesis is formulated which, for all intents and purposes, is general, even universal, in application. In the course of time, that hypothesis gains wide acceptance, and acquires the status of a generally, perhaps universally, applicable theory or even law.

Eventually, however, a hypothesis is promulgated in which the previously formulated and widely accepted "general" theory appears only as a special case in a gradation, still useful, however, in that now (relatively) limited field. Customarily, that later recognized gradation is designated by applying the prefix "non" to the accepted designation of the earlier recognized (and now special) case. The following quotation is pertinent, from a worker in the field of semantics.

"A non-Aristotelian system is not *anti*-Aristotelian. That is, it does not simply negate the rules Aristotle has formulated for the use of language. It simply

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† Subterrex, Houston, Texas.

points out that the rules are inadequate, because the language itself, to which they are applied (the language of syllogisms), is inadequate for describing the world as we know it today.

"The use of the term 'non-Aristotelian' is historically justified. Long before Korzybski's* formulation of the non-Aristotelian system, non-Euclidean geometries were invented, and modern physics, which includes the theory of relativity and quantum mechanics, is often referred to as *non-Newtonian* physics. Non-Euclidean geometries and non-Newtonian physics are not anti-Euclidean or anti-Newtonian. They are more general than the older systems and include them as special cases. Thus the geometry that describes the surface of a sphere may be formulated as a Riemannian (non-Euclidean) geometry. In small regions of the sphere (which can be considered as almost flat) Euclidean geometry can be applied successfully. If we are dealing with high velocities (such as sometimes are reached by subatomic particles), we must use Einstein's laws of motion to predict accurately, but where velocities are of ordinary magnitude, Newton's physics is quite adequate. All our engineering practice, except where nuclear physics is involved, still rests solidly on Newtonian physics and does very well."[1]

GENERAL COMMENTS

In the following discussion, reference is made to the recognition and resolution of anomalies without specifying the method by which that anomaly is recognized. The writer has purposely avoided such designation, since he plans, in subsequent studies, to present substantiating evidence for the non-structural working hypothesis from more than one type of prospecting.

Generally, these studies are directed at those prospecting methods in which the units measured are other than feet above or below sea level. Specifically, the writer is more interested in those prospecting methods in which some measure of control can be exercised over the depth of survey.

Objection may be raised to the apparent freehandedness with which the writer appears to postulate the observation of significant stratigraphic anomalies, and, in particular, their association with or even origin in petroleum accumulation.

In actual practice, the geophysicist often is called on to estimate his chances of success in a petroleum province, or in solving a prospecting problem, with respect to which he is without actual field experience. In such a situation, he usually relies upon his working hypothesis as a guide, and, postulating certain geologically reasonable subsurface conditions, makes an estimate of the kind and even the magnitude of the anomalies which might be expected.[2]

* A. Korzybski, *Science and Sanity*, Science Press Printing Co., Lancaster, Pa., 2nd Edition (1941).

[1] A. Rapaport, *Science and the Goals of Man*, Harper and Brothers (1950), 144.

[2] F. J. Agnich, "Geophysical Exploration for Limestone Reefs," *Geophysics, Vol. XIV, No. 4* (1949), 486–500.

Objection can be raised to the concept of significant stratigraphic anomalies on the basis of the following reasoning.

Virtually hundreds of petroleum accumulations have been discovered as a result of widespread geophysical exploration. Why, then, have such significant stratigraphic anomalies escaped general notice? Certainly the bulk of the literature on geophysical prospecting contains little reference thereto.

The possibility exists, of course, that significant stratigraphic anomalies have been observed but not recognized as such. Many of them may have been mistakenly identified as significant structural anomalies and resolved, incorrectly, on the basis of the geophysical structural working hypothesis. When put to the test of the drill, some may have resulted in failures rather than confirmations.

From the standpoint of the scientific method, geophysical prospecting has been more like an observational science (such as geology) than it has been like an experimental science (such as physics). That is, during the period when the geophysical prospecting methods were in the formative period of conception, introduction, and initial trial, it was impractical to conduct *critical* experiments designed to check and analyze the underlying assumptions on the basis of which the geophysical predictions were made (i.e., the resolution of the geophysical data into terms of economic significance).

Thus, while the geophysical prospectors took credit for the geophysical confirmations, sometimes they were not in position to account, adequately, for the geophysical failures. There is point, of course, in publishing the case history of a failure in which an adequate or even a novel explanation is offered for the failure; there is little point in publishing the case history of an unexplained failure. If statistics are to play a part in judging the validity of the concept of significant stratigraphic anomalies, the number of pertinent references thereto in the literature is less important than the number of inadequately explained geophysical failures.

In the quarter century which has passed since the introduction of geophysical prospecting, a wealth of subsurface information has become available; in many instances, then, information is at hand which may permit an adequate analysis of geophysical failures for which there was no satisfactory explanation at the time that the test well was abandoned.

As mentioned in earlier paragraphs, the non-structural working hypothesis is not *anti*-structural; rather, it is a more general working hypothesis which includes, as one sub-hypothesis, a close equivalent of the currently accepted geophysical working hypothesis. That is, the only possible merit in the non-structural working hypothesis is a greater usefulness; consequently, substantiating evidence for the non-structural hypothesis requires the demonstration of an adequate resolving effectiveness for, not only geophysical confirmations, *but also, past and current geophysical failures.*

In the following studies, then, the emphasis will be upon case treatments of geophysical failures where the subsurface conditions are known from subsequent

development. These known subsurface conditions will be compared with those postulated, or those which obviously would have been postulated, on the basis of the currently accepted geophysical structural working hypothesis, and also with those postulated on the basis of the proposed non-structural working hypothesis. Such comparisons may have only academic interest, but even "dry runs" have a recognized educational value.

THE MODUS OPERANDI OF PETROLEUM PROSPECTING

Currently, and over the past quarter century, by far the greater part of the effort in petroleum prospecting (other than drilling test wells) has consisted of the following steps.

1. Geophysical measurements are made at or just below the surface of the earth. Corrections are made for local irregularities, and a regional variation, if present, is recognized or removed.

2. If an anomaly then is evident, familiar in form and reasonable in magnitude (in terms of past experience and geological probability), it is interpreted or resolved into terms of possible economic significance by means of a postulated relationship to a condition considered necessary for, or an association presumed with, petroleum accumulation, i.e., by means of a working hypothesis.

Finding effectiveness and resolving effectiveness, then, are important components of petroleum prospecting. These have been defined[3] as follows.

"The *resolving* effectiveness of a given method is the extent to which the data can be translated into terms of economic significance. Thus, resolving effectiveness deals with the interpretation or the understanding of the data.

"The *finding* effectiveness is the ratio, at any given time, of the general magnitudes of the findable anomalies of possible economic significance to the general magnitudes of the current observational errors."

ACCEPTED THEORY AND WORKING HYPOTHESES IN PETROLEUM PROSPECTING

While his entry into the field of petroleum prospecting led to a revolution in the field of tactics, the geophysical prospector adopted the strategy of the petroleum geologist, his technological senior in the field of petroleum prospecting.

At about the time when geophysical prospecting was introduced, the anticlinal or structural theory of accumulation of oil and gas was ascendant in organized prospecting for petroleum.[4] In essence, that theory postulated that local geologic structure was a necessary (but not sufficient) condition for petroleum accumulation,* and so the basic strategy of organized petroleum pros-

[3] E. E. Rosaire, "Prospecting Effectiveness," *Geophysics, Vol. VI, No. 4* (1941), 428–448.

[4] J. V. Howell, "Historical Development of the Structural Theory of Accumulation of Oil and Gas," *Problems of Petroleum Geology*, Amer. Assoc. Petrol. Geol. (1934), 1–23.

* That anticlinal or structural theory of petroleum accumulation has evolved into a non-structural (i.e., more general than the structural) theory of petroleum accumulation, as evidenced by the following quotation.

"If we attempt to classify oil fields as being either structural or stratigraphic in type we find on

pecting was the search for and the recognition of local closed structure in sedimentary provinces.

This strategy carried over into geophysical petroleum prospecting, and the combination of geophysical tactics and geological strategy has resulted in the discovery of many geological structures and associated oil fields in various sedimentary provinces.

THE GEOLOGICAL STRUCTURAL WORKING HYPOTHESIS

When the geologist did his own structural prospecting, he appears to have made use of a working hypothesis, much like that which follows, in locating the initial test well on an anticline.

Given the following conditions.

A″. An untested anticline in a favorable sedimentary environment.

B″. Information which permits the determination or estimation of the shift of the structural apex with depth.

Then

1″. The most favorable location for an initial test well (in the absence of unfavorable information and other things being equal) is above the structural apex in the objective reservoir horizon, for there (according to the structural theory of petroleum accumulation) should be the maximum accumulation of petroleum, if present.

THE GEOPHYSICAL STRUCTURAL WORKING HYPOTHESIS

In his role as a structural prospector, the geophysicist applied his own structural working hypothesis,* much as follows.

Given a geophysical survey, with the following conditions.

A′. Adequate (structural) finding effectiveness, and

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one extreme such a field as Salt Creek, Wyoming, in which the trap may be said to be entirely structural—the local structural anomaly marking the edge of the pool on all sides. On the other hand, if we consider a shoestring-sand pool, such as is common in eastern Kansas, we find that the area of accumulation is altogether a function of the sand distribution and that local structure plays little or no part in the localization of the pool of oil. Between these two extremes, which might be taken, respectively, as 100 per cent structural and 100 per cent stratigraphic, we find every variation and gradation. As we approach the middle ground between these two types, it becomes increasingly difficult to determine whether the dominant trap-making factor is local structure or stratigraphic variation. The definition given, in practice, therefore, requires some qualification to assist in better usage of the two terms as applied to oil fields, particularly when both structural and stratigraphic variation are nearly equal as trap-making causes." (A. I. Levorsen, Foreword, *Stratigraphic Type Oil Fields*, Amer. Assoc. Petrol. Geol., 1941, ix–xii.)

Such a non-structural *theory of petroleum accumulation* should not be confused with a non-structural *working hypothesis for petroleum prospecting*.

* No attempt is made herein to describe or to question the experimental procedure by means of which this working hypothesis was validated. Suffice to say that several kinds of experiments have been conducted under widely differing structural conditions. As a result of these experimental tests, and the subsequent numerous confirmations, the geophysical structural working hypothesis has been generally accepted for particular geophysical methods operating under favorable conditions.

B′. Correction for local irregularities and elimination of regional variations.

C′. Across a lithologic structure underlying an appreciable thickness of lithology which is structurally undisturbed (within the limits of observational error for the method employed).

Then

1′. If the survey penetrates to or intercepts the underlying structure, a structural anomaly should be observed.

a) That observed anomaly should be conformable in shape, area, and magnitude to the lithologic structure at the effective depth of penetration of the survey.

b) Other things being equal, the maximum expression of that observed anomaly should overlie, or be properly oriented with respect to, the structural apex at the effective depth of penetration of the survey.

c) On the basis of the geological structural working hypothesis, and in the absence of unfavorable information, the maximum expression of that observed anomaly, then, should be, or should determine, the most *favorable* location for the initial test well.

2. If the survey does not penetrate to nor intercept the underlying lithologic structure, no anomaly should be observed.

From the standpoint of these studies, the critical limitation of the geophysical structural working hypothesis is the axiom that no anomaly with recognized significance in petroleum prospecting should be observed on a geophysical survey which penetrates or includes only structurally undisturbed lithology.

This application of the geophysical structural working hypothesis held even though the geophysicist did not measure his observed anomaly in terms of feet above or below sea level, but rather in seismic, electric, gravimetric or magnetic units. Either directly or by inference, the geophysicist or his client tended to or actually did translate the observed anomaly, measured in geophysical units, into lithologic structure measured in feet above or below sea level.[5]

The outstanding characteristic of geophysical petroleum prospecting, then, has been the general, inherent assumption that the potential economic significance of a geophysical anomaly in petroleum prospecting resided entirely in the possibility of its being resolved into lithologic structure, i.e., a local geological anomaly due to essentially vertical displacement in the lithology.

THE GEOPHYSICAL STRATIGRAPHIC WORKING HYPOTHESIS

The writer does not mean to imply that there was no geophysical working hypothesis to the effect that a variation in lithology, even without associated vertical displacement, could result in an observable anomaly. (A proper designation for such anomalies and the working hypothesis relied upon for their resolution is "stratigraphic," in that a "stratigraphic" anomaly is defined as "one in

[5] E. L. DeGolyer, "The Seductive Influence of the Closed Contour," *Economic Geology, Vol. 23, No. 6* (1928), 681–682.

which a variation in the stratigraphy is the chief element in the anomaly observed," paraphrasing Levorsen's definition of a "stratigraphic" trap.)[6]

Such a geophysical stratigraphic working hypothesis has been utilized in petroleum prospecting, but only in what might be called a negative way. After several large magnetic and/or gravimetric anomalies had been resolved on the basis of the geophysical structural working hypothesis, and had been unsuccessfully tested by the drill (i.e., no evidence of lithologic structure shown by subsurface studies), more or less general agreement was reached that such anomalies probably resulted from lateral variations in the basement complex without accompanying deformation of the sediments. Obviously, if such anomalies were not associated with sedimentary structure, they were not related to a condition accepted as necessary for petroleum accumulation and so had no potential economic significance. In such cases, then, resolution by the geophysical stratigraphic working hypothesis discouraged further prospecting for and/or testing of such (probably stratigraphic) anomalies.

REQUIREMENTS FOR FORMULATION OF A WORKING HYPOTHESIS

The requisite for a working hypothesis with a positive application in petroleum prospecting is the concept of a relationship of an observable anomaly to either a condition generally recognized as necessary for (the more popular), or an association postulated with, petroleum accumulation. (The writer considers and so designates such anomalies as "significant" in petroleum prospecting.)

In earlier papers,[7] the writer has described such a concept, and thereupon has based the non-structural working hypothesis under investigation. Two types of significant stratigraphic anomalies were described, the "near-deposit" and the "near-surface."

TYPES OF SIGNIFICANT STRATIGRAPHIC ANOMALIES

The near-deposit anomalies tend to be restricted to the immediate vicinity of the petroleum accumulation, perhaps within one to two thousand feet. Thus, if the petroleum accumulation occurs at a depth of several thousand feet, the near-surface sediments overlying the petroleum accumulation should appear to be stratigraphically normal.

The near-surface anomalies tend to occur in those near-surface sediments immediately adjacent to the outline of the near-surface projection of the petroleum accumulation, even though such sediments are structurally undisturbed.

If such significant stratigraphic anomalies can be observed and properly identified, they become proper and important prospecting objectives.

[6] A. I. Levorsen, "Stratigraphic versus Structural Accumulation," *Bull. Amer. Assoc. Petrol. Geol., Vol. 20, No. 5* (1936), 521–530.

[7] E. E. Rosaire, "Shallow Stratigraphic Variations over Gulf Coast Structures," *Geophysics, Vol. III, No. 2* (1938), 96–115.

Ibid., "Geochemical Prospecting for Petroleum," *Bull. Amer. Assoc. Petrol. Geol., Vol. 24, No. 8* (1940), 1400–1433.

The translation or resolution of significant structural *and* stratigraphic anomalies, together with their possible combinations, then requires a working hypothesis more general than the previously and currently accepted geophysical structural working hypothesis, i.e., a *non-structural* working hypothesis is required for the resolution of significant anomalies with characteristics which may be structural, stratigraphic, or "mixed," i.e., stratigraphic-structural.

THE NON-STRUCTURAL WORKING HYPOTHESIS FOR PETROLEUM PROSPECTING

Given the following general conditions.

A geophysical survey with

A. Adequate (structural and/or stratigraphic) finding effectiveness, and,

B. Corrected for local irregularities and regional variation.

Then a gradation in types of anomalies may be observed. At one extreme is the "pure" structural anomaly, originating wholly in lithologic structure. At the other extreme is the "pure" stratigraphic anomaly, originating wholly in stratigraphic variations in the (primary) lithology associated with the presence of petroleum accumulation. In between may be every possible variation, depending upon the relative magnitude of co-existing structural and stratigraphic anomalies, which the writer classifies as "mixed," or "stratigraphic-structural." Obviously, the non-structural working hypothesis reverts to a special structural working hypothesis in the absence of any observable significant stratigraphic variation associated with the presence of petroleum accumulation. (Thus, the special structural working hypothesis is the equivalent of the currently accepted geophysical structural working hypothesis.) Similarly, the non-structural hypothesis reverts to a special stratigraphic working hypothesis in the absence of any observable significant anomaly which originates in lithologic structure.

Resolution by the non-structural hypothesis, then, depends upon the identification of the observed anomaly as "pure" structural, "pure" stratigraphic, or "mixed" stratigraphic-structural, and a working knowledge of two sub-hypotheses, the special structural and the special stratigraphic hypotheses.

THE SPECIAL STRUCTURAL WORKING HYPOTHESIS

Given the foregoing general conditions and the following special conditions.

C. Across a lithologic structure underlying an appreciable thickness of lithology which is structurally undisturbed (within the limits of observational error for the method employed).

D. Absence of any observable anomaly originating in stratigraphic variations in (primary) lithology associated with the presence of petroleum accumulation.

Then

1. If the survey penetrates to or intercepts the underlying lithologic structure, a structural anomaly should be observed.

a) That observed anomaly should be conformable, in shape, area, and mag-

nitude, with the lithologic structure at the effective depth of penetration of the survey.

b) Other things being equal, the maximum expression of that observed anomaly should overlie, or be properly oriented with respect to, the structural apex at the effective depth of penetration of the survey.

c) In the absence of unfavorable information, and on the basis of the geological structural working hypothesis, the maximum expression of that observed anomaly, then, should be, or should determine, the most *favorable* location for the initial test well.

2. If the survey does not penetrate to nor intercept the underlying structure, no (structural) anomaly should be observed.

Note that the only difference between the special structural and the geophysical structural working hypotheses is the inclusion in the former of the special condition (D) "absence of any observable anomaly originating in stratigraphic variations in (primary) lithology associated with the presence of petroleum accumulation."

THE SPECIAL STRATIGRAPHIC WORKING HYPOTHESIS

Given the foregoing general conditions and the following special conditions.

E. Across a sedimentary column which is stratigraphically normal except for the presence of both a near-surface and a near-deposit significant variation in (primary) lithology associated with petroleum accumulation; this latter at a depth great enough so that the near-deposit significant stratigraphic variation is below and separated from the near-surface significant stratigraphic variation.

F. Absence of any observable anomaly originating in lithologic structure. (One form of this condition occurs where the petroleum accumulation is associated with a stratigraphic trap.)

Then

3. If the survey penetrates to a depth great enough to intercept the near-deposit significant variation in lithology, a *near-deposit* significant stratigraphic anomaly should be observed.

a) That observed anomaly should be conformable in depth, shape, area, and magnitude with the near-deposit significant variations in lithology at the effective depth of penetration of the survey.

b) Other things being equal, the maximum expression of the observed anomaly should overlie, or be properly oriented with respect to, the maximum expression of the near-deposit significant variation in lithology at the effective depth of penetration of the survey.

c) In the absence of unfavorable information, the maximum expression of that observed anomaly should be, or should determine, the most favorable location for a test well, for that location should be immediately above the maximum expression of the near-deposit significant variation in lithology.

4. If the survey penetrates the near-surface beds but does not intercept the

underlying near-deposit significant variation in lithology, a *near-surface* significant stratigraphic anomaly should be observed.

a) That observed anomaly should be conformable with the outline of the underlying petroleum accumulation.

b) The maximum expression of that observed anomaly, other things being equal, should occur adjacent to the surface projection of the outline of petroleum accumulation.

c) In the absence of information to the contrary, the maximum expression of that observed anomaly should be an *unfavorable* location for a test well.

d) That observed anomaly should bear no relationship to the depth of petroleum accumulation.

A SPECIAL STRATIGRAPHIC-STRUCTURAL WORKING HYPOTHESIS

An attempt could be made to formulate a working hypothesis applicable to the resolution of "mixed" or "stratigraphic-structural" anomalies. Levorsen[8] pointed out, with respect to structural and stratigraphic traps, that "as we approach the middle ground between these two types, it becomes increasingly difficult to determine whether the dominant trap making factor is local structure or stratigraphic variation." Certainly, an equally difficult problem may confront the prospector who attempts to determine whether an observed anomaly is structurally dominant, structural-stratigraphic, stratigraphic-structural, or stratigraphically dominant, prior to test by the drill. (Once the subsurface conditions have been revealed by the drill, however, it may be possible to determine the relative magnitudes of the structural and stratigraphic effects in the case of a mixed anomaly.)

In view of these considerations, no attempt has been made to formulate a special stratigraphic-structural working hypothesis.

SIMILARITIES AND DIFFERENCES

Note the following similarities and differences between the corollaries of the various working hypotheses under study.

SIMILARITIES

For all practical purposes, 1 a, b, and c of the *special structural* working hypothesis are the equivalents of 3 a, b, and c of the *special stratigraphic* working hypothesis (those applicable to the near-deposit significant variation in lithology), even down to the corollary that the maximum expression of the anomaly should be, or should determine, the most favorable location for the test well. Earlier, 1 a, b, and c for the *special structural* working hypothesis were shown to be the equivalents of similar corollaries of the currently accepted *geophysical structural* working hypothesis.

[8] A. I. Levorsen, Foreword, *op. cit.*

DIFFERENCES

However, note the differences between 2 and 4. Thus (in the absence of any observable significant stratigraphic anomaly), if a survey does not intercept an underlying lithologic structure, an anomaly *should not* be observed. However (in the absence of any observable significant structural anomaly), if a survey does not intercept an underlying near-deposit significant stratigraphic variation in lithology, an anomaly *may* be observed, i.e., a near-surface significant stratigraphic anomaly. Its characteristics (observable magnitude, depth relationship, shape or configuration, and orientation of maximum expression) are such as to make this "structurally forbidden" anomaly unique when compared with the equivalent characteristics of the previously described familiar anomalies, as shown in the following table.

TABLE 1

DIFFERENCES BETWEEN "FAMILIAR" AND "UNIQUE" ANOMALIES

Characteristic	Familiar Anomaly	Unique Anomaly
Postulated by (Working Hypothesis)	Geophysical Structural Special Structural Special (Near-Deposit) Stratigraphic	Special (Near-Surface) Stratigraphic
Depth Indicated by Anomaly	Significant	Not Significant
Shape	Conformable with Significant Area	Conformable with Outline of Significant Area
Orientation of Maximum Expression	Above Center of Significant Area	Above Edge of Significant Area
Maximum Expression	Most Favorable Location for Test Well	Unfavorable Location for Test Well

Another important difference is postulated if different depths of survey are considered.

In the case of a shallow and a deep survey, the special *structural* hypothesis postulates that a change in *absolute magnitude* of an anomaly may take place, from zero magnitude on a shallow survey to an observable magnitude on a deep survey, providing that only the latter survey intercepts an underlying lithologic structure.

However, in the case of a shallow and a deep survey, the special *stratigraphic* hypothesis postulates that a change in *type* of anomaly may take place, from a unique, structurally forbidden, near-surface, significant stratigraphic anomaly observed on the shallow survey to an anomaly with the (practical equivalents of the) characteristics of the more familiar structural type, providing that only the deep survey intercepts an underlying, near-deposit, significant variation in lithology.

These similarities and differences must be given consideration in planning critical experiments designed to test the corollaries from the two hypotheses at

issue, the geophysical structural and the non-structural working hypotheses.

As pointed out, the characteristics of the near-deposit significant stratigraphic anomaly are, in many respects, the practical equivalents of the characteristics of the structural type of anomaly anticipated by the geophysical structural working hypothesis, so that unquestioned differentiation of those two types may be difficult. On the other hand, some characteristics of the near-surface significant stratigraphic anomaly are unique, such as the observable magnitude on a shallow survey, configuration, orientation of maximum expression, and change in configuration with depth.

One critical test of the validity of the non-structural hypothesis, then, would be the identification, beyond reasonable doubt, of near-surface significant stratigraphic anomalies on the basis of their postulated unique characteristics.

The writer wishes to express his indebtedness to Mr. Forest Rosaire and Dr. L. W. Blau for their pertinent comments and criticisms; these contributed materially to the development of the basic concepts in this study.

AN APPROXIMATE CORRECTION METHOD FOR REFRACTION IN REFLECTION SEISMIC PROSPECTING*

TH. KREY†

ABSTRACT

Equations are derived and discussed to compute approximate corrections which must be applied to the results obtained by the classical methods of computing and constructing data in reflection seismic prospecting, (this includes the method of construction of seismic image point and the method of seismic prospecting using zero-spread time) to correct for refraction. In addition, the influence of refraction on the determination of average velocity as obtained by applying the time-square distance-square curve (Time-Delta-Time Velocity) is analyzed.

INTRODUCTION

The effect of refraction on reflection data has been discussed in several papers (Slotnick, 1936) (Stulken, 1945) (Rice, 1949) (Houston, 1939) (Waters, 1941). However, only the case of horizontal equi-velocity stratification is considered (Slotnick, 1936). In addition, in most cases a special velocity distribution is assumed, e.g., a linear or parabolic one (Stulken, 1945) (Rice, 1949). Geologic conditions in northwest Germany, however, are of such a nature that computations can be only occasionally based on such simplified assumptions. Therefore, the problem of refraction of the wave paths has to be attacked on more general conditions for this area. Some time ago the author (1949) published formulas without their derivation, which permitted making approximate allowance for the refraction effect on wave rays reflected in themselves. In addition, at the meeting of the "Geophysikalische Gesellschaft in Hamburg" at Clausthal, in September 1949, the author showed in which way refraction will approximately affect the course of the reflection time-distance curve and what effect the refraction has on the determination of average velocity as based on the time-square distance-square curve (Time-Delta-Time Velocity) (Heiland, 1933) (Menzel, 1948). In the following discussion, a mathematical derivation will be given in such general terms as to encompass and to expand the results of the two aforesaid papers. Furthermore some practical examples are presented demonstrating the value of the formulas obtained.

ASSUMPTIONS AND NOTATIONS

It is assumed that observations are made only at right angles to the strike. Therefore, we are dealing with a two-dimensional problem (Fig. 1). Let x be the horizontal coordinate with positive direction to the right and y the vertical coordinate with positive direction downward, $y=0$ coinciding with the surface. The velocity of wave propagation $v=v(x, y)$ may be dependent not only on the

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depth y but also in the horizontal coordinate x as indicated by the manner in which the term is written. However, the angle $j(x, y)$ between the curve $v(x, y) = \text{const.}$ and the horizontal line, at point (x, y) is assumed to be so small that third and higher powers of j may be ignored. This, of course, presupposes that

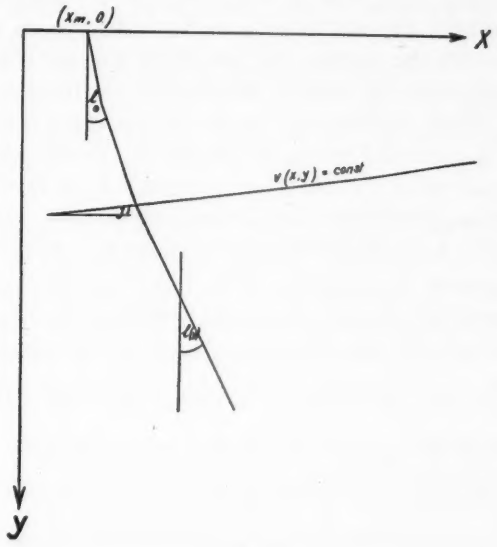

FIG. 1

(x, y) is not a singular point of the family of curves $v(x, y) = \text{const.}$ The following expression then holds:

$$j = (\partial v/\partial x)/(\partial v/\partial y), \tag{1}$$

with j being considered positive in a counter-clockwise direction. Besides, discontinuities in $v(x, y)$ should be admitted. However, there should be only simple breaks (*Sprünge*) along any lines whose slope toward the horizontal is required to be small and of the same order as j. This slope is also to be denoted by j. Thus, at points of continuities and discontinuities $v(x, y)$ the function $j(x, y)$ is defined in different ways. The total of the values of $v(x, y)$ is confined by a maximum and a positive minimum where practical values may always be chosen ranging from 6,000 m/sec (19,684 ft/sec) and 1,500 m/sec (4,921 ft/sec).

Let $s(t, x)$ be the inverse function of

$$t/2 = \int_0^s dy/v(x, y), \tag{2}$$

$s(t, x)$ represents the family of curves (or curve in case of $\partial s/\partial x = 0$) (Haarstick, 1943–48), on which the computation is usually based. Instead of $s(t, x)$ the so-called average velocity

$$\bar{v}(t, x) = s(t, x)/(t/2) \tag{3}$$

is also used.

PATH OF A RAY NOT DEVIATING TOO FAR FROM THE VERTICAL

Let us now consider a ray starting from the point $(x_m, 0)$ and, at this point forming the angle l_0 with the vertical. At the depth y where the ray will have the abscissa $x(y)$ the angle with the vertical will be $l(y)$, so that $l(0) = l_0$. l_0 is assumed to be so small that fourth and higher powers of this value may be dropped. Because of the limitation of v and of the statement on the magnitude of j, it is evident that the same powers of $l(y)$ can also be neglected. As terms of third order of j are to be dropped, as pointed out in the foregoing section, j is assumed to be of less magnitude than l_0. Accordingly the terms lj^2 and l^2j may be neglected, but the term l^3 cannot be ignored. In considering the following approximations it should be kept in mind that dl and dj are to be considered like l and j themselves.

Let us now start off with the differential form of the refraction law

$$\sin (l + dl - j)/\sin (l - j) = (v(x, y) + dv)/v(x, y)$$

Because of the possible neglect of terms as stated before it follows that

$$d \sin (l - j) = (dv/v) \sin (l - j) - dj. \tag{4}$$

Now if ι is the variable of integration associated with j, and if $v(x_m, 0) = v_0$, it is evident that

$$\sin (l - j) = (v/v_0) \sin (l_0 - j_0) - v \int_{j_0}^{j} d\iota/v \tag{5}$$

is a solution of equation (4), where $j_0 = j(x_m, 0)$.

Equation (4) has only one solution, if an initial condition is known. This condition is defined by $l(0) = l_0$ and the solution given in equation (5) is the only possible one. It may be added that discontinuities in v and j will not substantially affect these considerations, and equation (5) will remain correct.

Because of the assumed small variations of l and j it is sufficient to carry out the integration of the term

$$\int_{j_0}^{j} d\iota/v$$

along the vertical, with x kept constant, e.g. $x = x_m$, although strictly the integration should be carried out properly along the curved path. This results from the following considerations.

If η denotes the variable of integration associated with y

$$x(y) - x_m = \int_0^y d\eta \operatorname{tg} l(\eta)$$

is of the same order as $l(y)$. According to equation (1) $\partial v/\partial x$ is of the same order as j, and di is also of the same magnitude as j. Therefore, it is recognized easily that the given simplification of the path of integration introduces only an error of the order lj^2. Hereby it is assumed, however, that the lines of discontinuities of the term $v(x, y)$ between the two paths of integration are nearly linear and not intersecting.

Using equation (1) we obtain by partial integration

$$v\int_{i_0}^{i} di/v = j(y) - j_0 v/v_0 - v\int_0^{y} \partial/\partial x(1/v)d\eta. \tag{6}$$

Now, if equation (2) is differentiated with respect to x, with t constant, and the integration variable y is replaced by η, we have

$$0 = (1/v(x, s))\partial s(t, x)/\partial x + \int_0^{s} \partial/\partial x(1/v)d\eta. \tag{7}$$

From equations (6) and (7), with $s=y$, it follows

$$v\int_{i_0}^{i} di/v = j(y) - j_0 v/v_0 - (\partial s/\partial x)_{s=y,\, x=x_m}. \tag{8}$$

Therefore, $\partial s/\partial x$ is of the same order as j.

The derivation of equation (8) carried out above contains the assumption that the term $v(x, y)$ may be continuously differentiated. However, if the function $v(x, y)$ can not be differentiated continuously it can always be approximated by a continuously differentiable function, so that variations on the right- and left-hand side of equation (8) are, absolutely, less than any positive figure δ. Therefore, equation (8) is of general character.

Now, from equation (5), because

$$\sin(l - j) = \sin l - j,$$

it follows that

$$\sin l = (v(x, y)/v_0)\sin l_0 - (\partial s/\partial x)_{s=y,\, x=x_m}. \tag{9}$$

If $d\sigma$ denotes the element of line on the (curved) ray concerned and S the length of the ray between points $(x_m, 0)$ and (x, y) then

$$x - x_m = \int_0^{S} \sin(l(\eta))d\sigma, \tag{10}$$

and

$$y = S - (1/2)\int_0^{S} \sin^2(l(\eta))d\sigma. \tag{11}$$

On introducing the expression

$$M(f(y)) = (1/y)\int_0^y f(\eta)d\eta, \tag{12}$$

and after using $d\sigma=(1+(1/2)\sin^2 l)\,dy$, it follows that

$$x - x_m = \left\{(\sin l_0/v_0)yM(v) + (1/2)(\sin^3 l_0/v_0^3)yM(v^3) - yM(\partial s/\partial x)\right\}_{x=x_m} \tag{13}$$

since the curved path of integration may again be replaced by the straight path (see explanations between equations (5) and (6)!).

Furthermore it follows that

$$y=S\left\{1-(1/2)(\sin^2 l_0/v^2)M(v^2)+(\sin l_0/v_0)M(v\cdot\partial s/\partial x)-(1/2)M((\partial s/\partial x)^2)\right\}_{x=x_m,y=S} \tag{14}$$

and finally by substituting equation (14) into equation (13)

$$x - x_m = S\left\{(\sin l_0/v_0)M(v) + (1/2)(\sin l_0/v_0^3)\left\{M(v^3) - M(v)M(v^2)\right\} - M(\partial s/\partial x)\right\}_{x=x_m,y=S}. \tag{13a}$$

RAY REFLECTED IN ITSELF AND DEPARTURE FROM THE CLASSICAL METHOD OF CONSTRUCTION (CONSTRUCTION OF SEISMIC IMAGE POINT)

The ray now considered is one reflected in itself. The coordinates of the shot point are x_s, 0, those of the point of reflection X, Y. Let the angle of dip of the reflecting surface be i. The reflection time distance curve $T(x)$ is given in a certain neighborhood of $x=x_s$, consequently $(dT/dx)_{x=x_s}$ is known. Then with $x=X$ and $y=Y$ equations (13a) and (14) yield the location of the point of reflection, and equation (9a) with $l=i$ contains the expression for the dip of the reflecting surface, on using

$$\sin l_0 = -v(x_s, 0)(dT/dx)_{x=x_s} = -v_0(dT/dx)_{x=x_s}. \tag{15}$$

If the reflection concerned is constructed or computed according to the classical method of finding the seismic image point when applying the average velocity $\bar{v}$, then it holds for the dip $\bar{i}$ that

$$\sin \bar{i} = -\bar{v}(dT/dx)_{x=x_s}. \tag{16}$$

Using equations (15) and (16) equation (9a) becomes

$$\sin \bar{i} = (v(x_s, Y)/\bar{v})\sin \bar{i} - (\partial s/\partial x)_{s=Y,\,x=x_s}. \tag{17}$$

If the *same length S of the ray is applied*, the following holds for the coordinates $\overline{X}$ and $\overline{Y}$ obtained by construction of the seismic image point

$$\overline{X} - x_s = S\cdot\sin \bar{i}$$
and
$$\overline{Y} = S(1 - (1/2)\sin^2 \bar{i}). \tag{18}$$

Hence equation (13a) and (14) become

$$X - \overline{X} = S\{\sin \bar{\imath}(M(v)/v - 1) + (1/2)\,(\sin^3 \bar{\imath}/\bar{v}^3)[M(v^3) - M(v^2)M(v)] - M(\partial s/\partial x)\}_{x=x_s,y=S} \quad (19)$$

and

$$Y - \overline{Y} = S\{-(1/2)\sin^2 \bar{\imath}(M(v^2)/\bar{v}^2 - 1) + (\sin \bar{\imath}/\bar{v})M(v\partial s/\partial x) - (1/2)M((\partial s/\partial x)^2)\}_{x=x_s,y=S} \quad (20)$$

or

$$X - \overline{X} = \overline{X}(M(v)/\bar{v} - 1) - SM(\partial s/\partial x) + (1/2)\,(\overline{X}^3/S^2)[M(v^3) - M(v^2)M(v)]/\bar{v}^3) \quad (19a)$$

$$Y - \overline{Y} \cong -(\overline{X}^2/S)(M(v)/\bar{v} - 1) + \overline{X}M(\partial s/\partial x) - (1/2)SM((\partial s/\partial x)^2). \quad (20a)$$

To the derivation of (19a) and (20a) the following two equations, which are approximately valid, have been applied.

$$M(v^2)/\bar{v}^2 - 1 = 2(M(v)/\bar{v} - 1)$$

and

$$(1/\bar{v})M(v\partial s/\partial x) = M(\partial s/\partial x).$$

Now, equations (17), (19) and (20) represent a generalization of the equations (1), (2) and (3) published previously (Krey, 1949) whose derivation is given herewith.

Now, for S the reflection time T will be substituted. This is done by using the relations

$$T/2 = \int ds/v = \int (dy/v)(1 + (1/2)\sin^2 l)$$

and

$$S = \int ds = \int dy(1 + (1/2)\sin^2 l)$$

and in applying equation (9a). Then it follows that

$$S = T\bar{v}^x/2[1 + (1/2)\,(\sin^2 l_0/v_0^2)\{M(v^2) - \bar{v}M(v)\} - (\sin l_0/v_0)\{M(v\partial s/\partial x) - \bar{v}M(\partial s/\partial x)\} + (1/2)\{M((\partial s/\partial x)^2) - \bar{v}M((\partial s/\partial x)^2/v)\}]_{x=x_s,y=Y \text{ or } S} \quad (21)$$

where

$$\bar{v}^x = \frac{Y}{\int_0^Y dy/v} \quad (22)$$

with the path of integration being identical with the curved ray. Generally it will be

$$\bar{v}^x = \bar{v}(x^x, Y)$$

with x^x representing a convenient value between X and x_s. In practice mostly

$$x^x = (X + x_s)/2$$

will be used.

Now, instead of equation (13a) and (14) we may write

$$x - x_m = (1/2)T\bar{v}^x\{(\sin l_0/v_0 M)(v) + (1/2)\,(\sin^3 l_0/v_0^3)[M(v^3) - \bar{v}M^2(v)] - M(\partial s/\partial x)\}_{x=x_m,\,y=T\bar{v}^x} \quad (23)$$

and

$$y = (1/2)T\bar{v}^x\Big\{1 - (1/2)\,(\sin^2 l_0/v_0^2)\bar{v}\cdot M\left(\frac{\partial s}{\partial x}\right) + (\sin l_0/v_0)\bar{v}M(\partial s/\partial x) - (1/2)vM((\partial s/\partial x)^2/v)\Big\}_{x=x_m,\,y=T\bar{v}^x}. \quad (24)$$

If these expressions are to be compared with those obtained by classic computation of the coordinates *in applying the same average velocity* $\bar{v}^x$, then S has to be replaced by $T\bar{v}^x/2$ in equation (18). Using equations (15) and (16) we obtain

$$X - \overline{X} = (1/2)T\bar{v}^x\{\sin \bar{\imath}(M(v)/v - 1) - M(\partial s/\partial x) + (1/2)\,(\sin^3 \bar{\imath}/\bar{v}^3)[M(v^3) - \bar{v}M^2(v)]\}_{x=x_s,\,y=(1/2)T\cdot\bar{v}^x} \quad (25)$$

and

$$Y - \overline{Y} = (1/2)T\bar{v}^x\{-(1/2)\sin^2 \bar{\imath}(M(v)/v - 1) + \sin \bar{\imath}M(\partial s/\partial x) - (1/2)\bar{v}M((\partial s/\partial x)^2/v)\}_{x=x_s,\,y=(1/2)T\cdot\bar{v}^x} \quad (26)$$

or designating $S=(1/2)T\bar{v}^x$

$$X - \overline{X} = \overline{X}(M(v)/\bar{v} - 1) - SM(\partial s/\partial x) + (1/2)\,(\overline{X}^3/\overline{S}^2)[M(v^3) - \bar{v}M^2(v)]/\bar{v}^3 \quad (25a)$$

and

$$Y - \overline{Y} = -(\overline{S} - \overline{Y})(M(v)/\bar{v} - 1) + \overline{X}M(\partial s/\partial x) - S(1/2)\bar{v}M((\partial s/\partial x)^2/v). \quad (26a)$$

Here attention is directed to the fact that equations (19) and (20), on the one hand, and equations (25) and (26) on the other hand, are not homologous, since in the first case equal length of ray and in the second case equal average velocity are presupposed.

Containing the unknown X and Y the term $\bar{v}^x$ can not be determined in a simple way. In a previous paper (Krey, 1949), reference was made to a procedure of iteration that might be applied, and which will be described again. It begins with the average velocity $\bar{v}_0$

$$\bar{v}_0 = s(T, x_s)/(T/2) \tag{27}$$

which will be determined correspondingly to equation (3). In substituting $\bar{v}_0$ for $\bar{v}^x$, X_0 and Y_0 are obtained by equations (23) and (24). This procedure of computation is called the primary step. Then $\bar{v}^x$ is chosen as

$$\bar{v}_1 = v((X_0 + x_s)/2, Y_0)$$

and X_1 and Y_1 are determined by means of equations (23) and (24), etc. Generally it is

$$\bar{v}_n = \bar{v}((X_{n-1} + x_s)/2, Y_{n-1}). \tag{28}$$

As a rule, however, for dips that are extremely steep it will be sufficient to apply the procedure of iteration but once.

Although several examples were discussed in the previous paper (Krey, 1949) to demonstrate the effect of the refraction corrections according to equations (1), (2) and (3) given there, two of those examples are represented here again to which single iteration of average velocity and corrections according to equations (17), (25) and (26) have been applied. This appeared to be necessary, since the aforesaid equations in this paper represent a certain improvement of those given previously.

Figure 3 illustrates an example valid for $\partial s/\partial x \doteq 0$, and Figure 4 another one with $i\partial s/\partial x < 0$, i.e., the sign of $\partial s/\partial x$ in Figure 4 is such that the absolute value of the correction terms will become rather great. w denotes the true position of the element of reflection, 0 the uncorrected value of the primary step obtained by the construction of the image point, and 1 the result obtained if after one iteration of velocity the refraction, corrections, equations (17), (25) and (26) are applied. In the examples given in Figures 3a, 4a and 4a′ showing true dips not exceeding 26 degrees the departure of the values corrected, denoted by 1, from the true location of the element of reflection, denoted by w, is so small that it can not be demonstrated in the figures represented. In Figures 3b and 4b the true dip of 56 degrees is already rather steep. Therefore a certain discrepancy remains between the true dip of the element of reflection w and the one obtained by applying corrections. However, a substantially improvement against the primary step 0 is evident. Besides, in comparing Figures 3a, 4a and 4a′ it is seen that in the case of $\partial s/\partial x = 0$ (and further mostly in the case of $i\partial s/\partial x > 0$) the correction for location according to equations (25) and (26) may be ignored. But so far, this does not hold for the correction for dip, equation (17).

RAY REFLECTED IN ITSELF AND DEPARTURE FROM THE DATA OBTAINED BY THE SEISMIC SOUNDING METHOD

In a previous paper (Krey, 1949) it was shown how refraction will act if not the method of construction of the image point but the method of seismic sounding is used for the representation of the data. However, no equations for a generally valid treatment were given, but this will be given here.

In the sounding method the travel time $T = T(x, x_s)$ has to be considered not only a function of the observation point $(x, 0)$ but also of the shot point $(x_s, 0)$. The zero-spread times

$$T(x_s, x_s) = T^z(x_s)$$

are the decisive data.

Now it holds that

$$dT^z(x_s)/dx_s = dT(x_s, x_s)/dx_s = 2(\partial T/\partial x)_{x=x_s} \tag{29}$$

as may easily be derived from Figure 2. With respect to the values obtained by means of the sounding method the following notations are introduced. i^z denotes

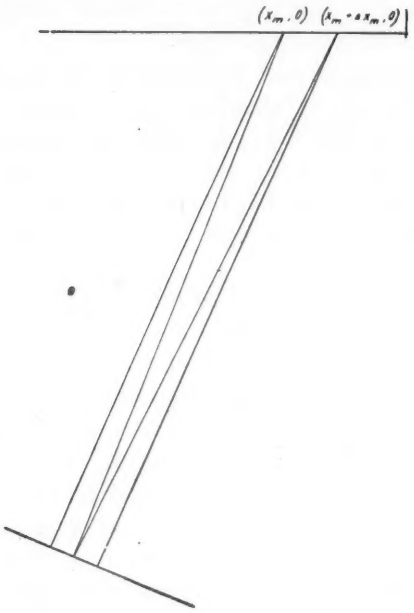

FIG. 2

the dip of a layer, X^z and Y^z the coordinates of the point of reflection. The length S of the ray reflected in itself is then

$$S = S(x_s, T^z(x_s), dT^z(x_s)/dx).$$

If the term d^2T^z/dx_s^2 is neglected—this means that no notable curvature of the reflecting surface is supposed—we may write

$$\sin i^z = -dS/dx_s = -\partial S/\partial x_s - (\partial S/\partial T^z)(dT^z/dx_s).$$

By using equations (29), (2), (16), (17) and because of

$$\partial S/\partial T^z = (1/2)v(X, Y)$$

we obtain the following relation

$$\sin i^x = + (v(x_s, Y)/\bar{v}) \sin \bar{\imath} - (\partial s/\partial x)_{s=Y,\, x=x_s}$$

and

$$\sin i^x = \sin i. \tag{30}$$

Hereby, among others, we availed ourselves of considerations similar to those made between equations (5) and (6) and in deriving equation (9a). Since

$$X^x = S \sin i^x = (1/2) T^x \bar{v} \sin i^x$$

and

$$Y^S = S(1 - (1/2) \sin^2 i^x) = (1/2) T^x \bar{v} [1 - (1/2) \sin^2 i^x]$$

we obtain equations (31) and (32) for the point of reflection based on equations (23) and (24)

$$\begin{aligned} X - X^x &= \frac{1}{2} T\bar{v}^x \left\{ \sin \bar{\imath} \, \frac{M(v) - v}{\bar{v}} - M\left(\frac{\partial s}{\partial x}\right) + \frac{\partial s}{\partial x} \right. \\ &\quad \left. + \frac{1}{2} \frac{\sin^3 \bar{\imath}}{\bar{v}^3} [M(v^3) - \bar{v} M^2(v)] \right\} \\ &= \frac{1}{2} T\bar{v}^x \left\{ \sin i^x \, \frac{M(v) - v}{v} - M\left(\frac{\partial s}{\partial x}\right) + \frac{\partial s}{\partial x} \, \frac{M(v)}{v} \right. \\ &\quad \left. + \frac{1}{2} \frac{\sin^3 i^x}{v^3} [M(v^3) - \bar{v} M^2(v)] \right\} \end{aligned} \tag{31}$$

and

$$\begin{aligned} Y - Y^x &= \frac{1}{2} T\bar{v}^x \left\{ \frac{1}{2} \cdot \frac{\sin^2 i}{\bar{v}^2} [v^2 - \bar{v} M(v)] \right. \\ &\quad - \frac{\sin \bar{\imath}}{\bar{v}} \left[v \, \frac{\partial s}{\partial x} - \bar{v} M\left(\frac{\partial s}{\partial x}\right) \right] \\ &\quad \left. + \frac{1}{2} \left[\left(\frac{\partial s}{\partial x}\right)^2 - \bar{v} M\left(\frac{1}{v} \left(\frac{\partial s}{\partial x}\right)^2 \right) \right] \right\} \\ &= \frac{1}{2} T\bar{v}^x \left\{ \frac{1}{2} \, \frac{\sin^2 i^x}{v^2} [v^2 - \bar{v} M(v)] \right. \\ &\quad - \frac{\sin i^x}{v} \left[\frac{\bar{v} M(v)}{v} \, \frac{\partial s}{\partial x} - \bar{v} M\left(\frac{\partial s}{\partial x}\right) \right] \\ &\quad + \frac{1}{2} \left[- \frac{\bar{v} M(v)}{v^2} \left(\frac{\partial s}{\partial x}\right)^2 \right. \\ &\quad \left. \left. + 2 \, \frac{\bar{v} M(\partial s/\partial x)}{v} \cdot \frac{\partial s}{\partial x} - \bar{v} M\left(\frac{1}{v} \left(\frac{\partial s}{\partial x}\right)^2 \right) \right] \right\} . \end{aligned} \tag{32}$$

These equations are based on an equal velocity $\bar{v}^{=}$, $T^{=}$ being replaced by T.

According to equation (30) the dip is obtained accurately by the sounding method which, among others, is a great advantage of the method. However, the discrepancy in the coordinates of location is much greater throughout the sounding method than with the method of construction of the image point, since $|M(v)-v|$ is throughout essentially greater than $|M(v)-\bar{v}|$. Therefore, at least in cases of step dip, the author (1949) has already recommended determination of the coordinates of the point of reflection by the method of construction of the image point and then connection of one point of reflection with the other. Thus, in most cases the application of corrections for refraction may be left out, whereas

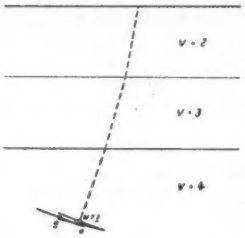

FIG. 3a

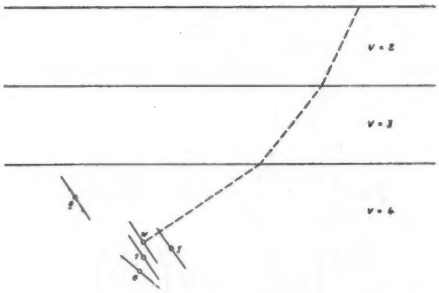

FIG. 3b

when using the sounding method proper, it would not be possible to ignore the correction for location according to equations (31) and (32). On the other hand, when using the method of construction of the image point proper the refraction correction for dip according to equation (17) would have to be applied.

In addition to the aforedescribed data obtained by the construction of the image point the Figures 3 and 4 contain the primary step data (designated as $\underline{o}$) which would be obtained by using the sounding method with shot points at an infinitesimal distance, and the data (designated as $\underline{1}$) resulting therefrom by single iteration and by using the correction equations (31) and (32). Figures 3a and 3b confirm the fact that location is better represented by the primary step of the method of construction of the image point than by the primary step of the sounding method. However, in Figure 4 the discrepancies between o and w, and

between o and w are of about the same magnitude because of the terms containing $\partial s/\partial x$, but in practice this should rarely happen. Besides, in all cases, except for Figure 3a, where 1 practically coincides with w as 1 does with w, a greater discrepancy exists between 1 and w than between 1 and w. Therefore, the advice to determine the location of the point of reflection by the method of construction of the image point proves to be correct.

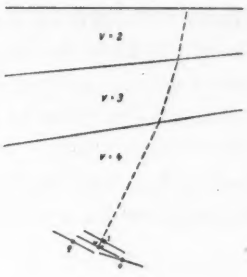

FIG. 4a

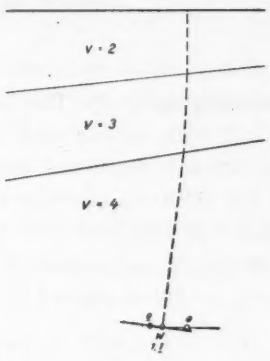

FIG. 4a'

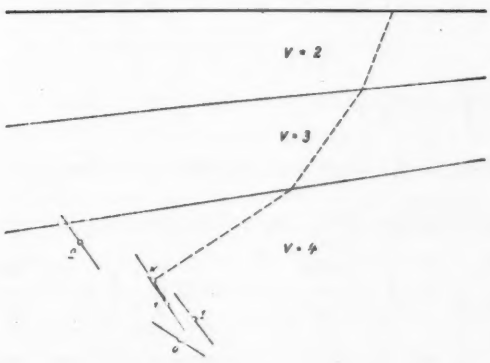

FIG. 4b

THE REFLECTION TIME-DISTANCE CURVE AND ITS APPLICATION TO THE DETERMINATION OF AVERAGE VELOCITY
(Time-Delta-Time Velocity)

In Figure 5 a generally reflected ray, one not reflected in itself, may now be considered. Let P_m, with the coordinates (x_m, o) be the point where the ray emerges at the surface, p_0, with the coordinates (o, o) the shot point and Q_m, with the coordinates (X, Y) the point of reflection. The angle of dip of the reflecting surface will be denoted i, as before. Let $\phi(y)$ be the angle between the ray emerging at P_m and the vertical at the depth y, and $\psi(y)$ the corresponding angle

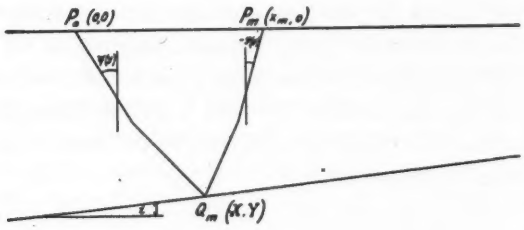

FIG. 5

of the ray submerging at P_0. The case of small angles will again be considered in this section but with *second* and higher powers of i and j, or $\partial s/\partial x$ respectively, being already neglected and with the terms ϕi, ϕj, ψi and ψj ignored; whereas, for the moment, allowance will still be made for the terms of third order in ϕ and ψ but not, however for such of fourth and higher order.

Now, if equation (9a) is applied, first, with $l=\phi$ and $x_m=x_m$ and second, with $l=\psi$ and $x_m=0$, and it is argued as in the case of equations (5) and (6) we obtain

$$\begin{aligned} i &= (1/2)\{\phi(Y) + \psi(Y)\} \\ &= (1/2)(v/v_0)\{\sin\phi(0) + \sin\psi(0)\} - (\partial s/\partial x)_{z=Y,\,x=0} \\ &\quad + (1/12)(v/v_0)^3\{\sin^3\phi(0) + \sin^3\psi(0)\}. \end{aligned} \tag{33}$$

Hence

$$\begin{aligned} x_m &= \int_0^Y dy\, tg\,\psi - \int_0^Y dy\, tg\,\phi \\ &= \{-2\sin\phi_0(0)/v_0 + 2(i + \partial s/\partial x)/v\}YM(v) - (\sin^3\phi_0(0)/v_0^3)YM(v^3). \end{aligned} \tag{34}$$

Similarly for the reflection time the following equation holds

$$T(x_m) = \int_0^Y \frac{dy}{v\cos\psi} + \int_0^Y \frac{dy}{v\cos\phi} = 2YM\left(\frac{1}{v}\right) + \frac{\sin^2\phi_0(0)}{v_0^2}YM(v). \tag{35}$$

From (34) and (35) we obtain by elimination of Y and using (15)

$$\begin{aligned} x_m &= \frac{\partial s/\partial x + i}{v}\,\frac{M(v)}{M(1/v)}\,T(x_m) + \frac{M(v)}{M(1/v)}\,T(x_m)\cdot\frac{dT}{dx_m} \\ &\quad + \frac{1}{2}\,T(x_m)\left(\frac{dT}{dx_m}\right)^3\frac{1}{M(1/v)}\left\{M(v^3) - \frac{M^2(v)}{M(1/v)}\right\}. \end{aligned} \tag{36}$$

Equation (36) is evidently the differential equation for the time-distance curve of the reflection arrivals with an approximate allowance for refraction. The expression

$$M(v^3) - M^2(v)/M(1/v)$$

evidently becomes zero if the function $v(x, y)$ is constant.

If the values of $v(x, y)$ are supposed not to vary too much the last term of equation (36) may also be neglected since this term is of third order and its factor remains small. If the third order terms in ϕ and ψ would have been completely ignored this would have resulted in too much of an approximation since in equation (36), $vT(0)$ could, then, generally be substituted for $T(x_m)$. Therefore the terms of third order in ϕ and ψ had to be considered hitherto.

$$(i + \partial s/\partial x)T(x_m) = (i + \partial s/\partial x)T(0)$$

also, may be inserted since $T(x_m) - T(0)$ is of the same order as $\phi^2+\psi^2$. Now we succeed in carrying out the integration of equation (36), and the following expression is obtained for the time-distance curve

$$x_m^2 - 2x_m[(i+\partial s/\partial x)/v](M(v)/M(1/v))T(x_0) = [M(v)/M(1/v)]\{T^2(x_m) - T^2(x_0)\}. \quad (37)$$

If refraction is completely neglected the time-distance curve of a reflected wave has the following well known form

$$x_m^2 - 2x_m i\bar{v}T(x_0) = \bar{v}^2\{T^2(x_m) - T^2(x_0)\}. \quad (38)$$

Equation (37) essentially differs from equation (38) in so far as $\bar{v}^2$ is replaced by

$$M(v)/M(1/v) = M(v)\cdot\bar{v}.$$

As is well known, the determination of $\bar{v}$ is now possible (Menzel, 1948) by means of three pairs of observational data $(x_m, T(x_m))$ and by eliminating i in equation (38). This method is known as velocity determination by means of the time-square distance-square law. In the American professional literature it is spoken of as time-delta-time velocity. In the speech presented at the meeting of the "Geophysikalische Gesellschaft in Hamburg" at Clausthal, in September 1949, the author mentioned the following most suitable arrangement for observations: Records are taken from shot point I in direction of shot point II over twice the distance between the two shot points, and from shot point II in direction of shot point I, also over twice the distance of the two shot points (Fig. 6). Such an arrangement of settings has the advantage that with each setting an equal extent in length of the reflecting surface is covered.

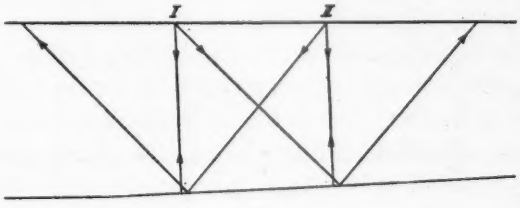

FIG. 6

On the strength of the comparison of equation (37) with equation (38) it is now known that not $\bar{v}$ but $\sqrt{\bar{v}M(v)} = \bar{v}$ is obtained. It can now easily be proved by means of Schwarz' lemma that $\bar{v} \geqq \bar{v}$. The value obtained for $\bar{v}$ will be always too great if no allowance is made for the effect of refraction.

With the following example the possible magnitude of the difference between $\bar{v}$ and $\bar{v}$ will be shown. The average velocity in Tertiary and Diluvium of North Germany is about 2,000 m/sec (6,560 ft./sec). Velocities in certain parts of Lower Saxony in the Upper Cretaceous have values of about 4,000 m./sec. (13,124 ft./sec.). With equal thickness of Diluvium and Tertiary, on the one hand, and Upper Cretaceous, on the other hand, it follows that $\bar{v} = 2{,}667$ m./sec. (8,750 ft/sec) and $\bar{v} = 2{,}830$ m/sec (9,284 ft/sec). The difference amounts, therefore, to 6 per cent. That is an amount which must be considered since the general error in measurements can be lowered to 1 to 3 per cent (Romberg, 1941).

The question now arises how the value of the correction

$$\Delta v = \bar{v} - \bar{v} \tag{39}$$

is determined. For this purpose a certain knowledge is necessary of the geological character and the individual velocities of the various beds overlying the surveyed reflecting surface. In many cases recourse may be taken to certain data on the velocity in top layers which are already known. In many other cases the reflecting surface to be investigated may still be overlain by other reflecting beds for which the method of the time-square distance-square curve might also be applicable to the determination of their average velocity. For a first approximation $\bar{v}$ is substituted for $\bar{v}$, and on this assumption, the average velocity of the strata *between* the

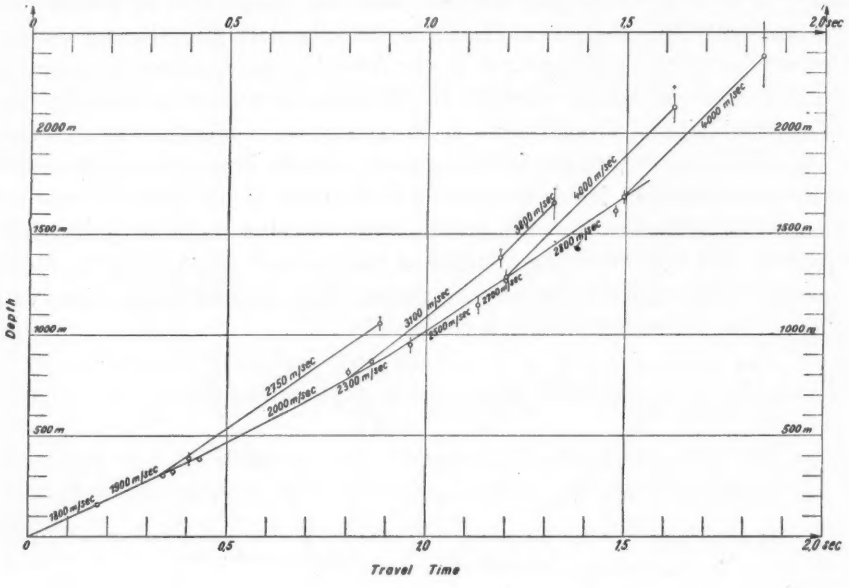

FIG. 7

reflecting surfaces is determined. Having calculated from this the value of Δv, $\bar{v}$ may be obtained. With these values for $\bar{v}$ the correction values Δv may be checked once more. In this way, employing one or two steps of iteration, a close approximation in the determination of Δv will mostly be obtained.

The method described above was carried out, among others, at different places in the area of the mouth of the Elbe river with respect to a horizon embedded in lower Upper Cretaceous (base of Turonian). A reflecting horizon in a higher position that could be used for the calculation of the refraction effect, equation (39), was on the base of the Tertiary. The total of the values thus obtained was plotted together as a family of time-distance curves (Fig. 7). The vertical bars on both sides of each observation point indicate the magnitude of possible error, supposing a possible error of 0.004 seconds in the determination of ΔT. In

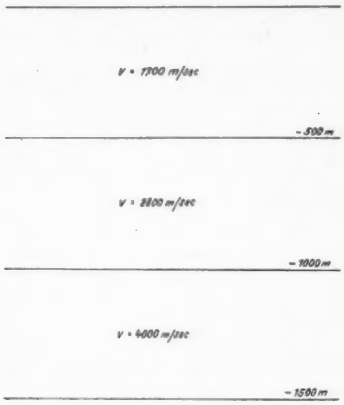

FIG. 8

the Tertiary the depth is only dependent on the reflection time and scarcely on the geological age of the strata traversed. Accordingly the values approximately fit a curve. The observation data from Upper Cretaceous, on the contrary, depend essentially on the position of the base of the Tertiary. As for the latter, the effect of refraction may also be seen from Figure 7, because the crosses indicate the uncorrected values. Besides it is obvious that the average velocity within the Upper Cretaceous is essentially dependent on the depth of the base of the Tertiary, namely in such a way that velocity is essentially increasing in the Upper Cretaceous with an increase in thickness of the overlying Tertiary strata.

The question of the effect of the refraction terms of *higher* powers on the determination of velocities by means of the time-square distance-square curve was examined by the author in an example of a horizontal reflecting bed. Figure 8 shows the assumed velocity distribution above the reflecting surface. In Figure 9 the abscissa denotes the distance up to which the reflection time is observed and the ordinate denotes the average velocity $\bar{v}(x)$, obtained by equation (38), hence

$$\bar{v}(x) = \sqrt{x^2/(T^2(x) - T^2(0))}. \tag{40}$$

Besides the function $\bar{v}(x)$ the two functions $\bar{v}_+(x)$ and $\bar{v}_-(x)$ are represented in Figure 9 which are obtained if $T(x)$ is decreased or increased by 0.004 seconds. These two curves shall approximately demonstrate the bounds of error in the determination of $\bar{v}(x)$. Obviously, there must exist a most pertinent distance for the determination of $\bar{v}$ and hence of $\tilde{v}$, which in the given example is about

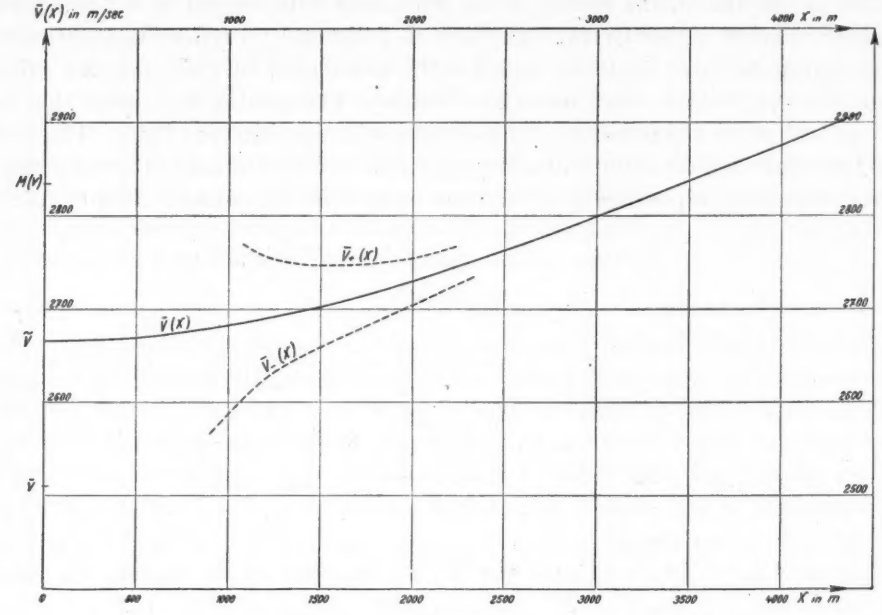

FIG. 9

$x = 1{,}600$ m (5,249 ft). It is evident that with smaller values of x the error resulting from the inaccuracies in timing will increase and with greater values of x the terms of higher powers representing the effect of refraction will at last weigh too heavily.

ACKNOWLEDGMENT

The author wishes to express his thanks to Dr. Lückerath and many other colleagues of the Seismos G.m.b.H., as well as to Professor Dr. L. Mintrop for the interest he has taken in the paper. Further the author wishes to thank Seismos G.m.b.H. for the permission to publish this paper and Mr. Tuchel for the translation of it.

BIBLIOGRAPHY

F. Haarstick, "Die Weg-Zeitkurve in der Reflexionsseismik," *Geologisches Jahrbuch*, Bd. 64 (1943–48) Herausgegeben von den Geologischen Landesanstalten.

Carl A. Heiland, *Gerl. Beiträge. Geophys. Ergänz. Hefte*, Heft 3 (1933).

E. C. Houston, "Seismic Paths Assuming a Parabolic Increase of Velocity With Depth," *Geophysics* (October 1939).

Th. Krey, *Erdöl und Kohle*, 2. Jahrgang, 7 (1949) 273.
H. Menzel, *Zeitschrift für Meteorologie*, Heft 11 (1948).
R. B. Rice, "A Discussion of Steep-Dip Seismic Computing Methods," *Geophysics* (April 1949 and January 1950).
F. Romberg, "The Probable Errors of Delta T Velocities," *Geophysics* (October 1941).
M. M. Slotnick, "On Seismic Computations with Applications," *Geophysics* (January and October 1936).
E. J. Stulken, "Effect of Ray Curvature Upon Seismic Interpretations," *Geophysics* (October 1945).
H. K. Waters, "A Numerical Method of Computing Dip Data Using Well Velocity Information," *Geophysics* (October 1939).

HYDROSTATIC LEVEL FOR ELEVATION SURVEYING*

KENNETH C. CRUMRINE† AND JOHN E. PALMER†

ABSTRACT

A hydrostatic level for elevation surveying has been developed which indicates differences in elevation by measuring the head of a column of water. It is essentially a differential pressure gauge connected by a length of water-filled plastic tubing to a water reservoir. The instrument is described and the results of a field test on 73 miles of traverse are given. A probable error of about 6 cm and a maximum error of 33 cm were found for closed loops of 3 to 5 miles after proration of closure errors. On unsupported traverses of 3 to 5 miles, application of a temperature correction appeared desirable and resulted in a probable error of about 10 cm and a maximum error of 52 cm. The range of the instrument is from minus to plus 10 meters and the least count is 2 cm. It is read to the nearest centimeter.

INTRODUCTION

The concept of hydrostatic pressure and its relation to the height of a column of practically incompressible liquid, apparently introduced in explanation of Archimedes' principle, can evidently be the basis of an instrument for elevation surveying. Such an instrument, called the hydrostatic level, which determines differences in elevation by measuring the head of a column of water, has been developed. It is essentially a differential pressure gauge connected by a length of water-filled plastic tubing to a water reservoir. The reservoir provides a reference level and the manometer indicates its own elevation with respect to this level.

The hydrostatic level was developed primarily for use in rugged brush-covered areas. In such areas, particularly in foreign geophysical operations, it has been found advantageous for one surveying crew to cut and map paths through the jungle, and for another crew to obtain vertical control at a later date. For such applications the hydrostatic level has two principal advantages over optical levels. First, it is faster because elevation differences up to plus or minus 10 meters can be read directly. Second, some time is saved clearing trails because a line of sight to a target is not necessary. It has been variously estimated that the speed of traverse with the hydrostatic level in such areas is from two to five times faster than with an optical level.

Accuracy tests have been made around loops on which the elevations of bench marks about one-half mile apart were known from optical leveling. The differences, or errors, between the hydrostatic level and optical level elevations at such bench marks were as follows. The probable error was about 6 cm and the maximum error was 33 cm for closed loops of 3 to 5 miles after proration of the

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closure errors. If the readings taken around loops were considered to simulate unsupported traverse data for which it would not be possible to prorate closure errors, it was found desirable to apply a simple temperature correction to the data. The resultant elevations on simulated unclosed and unsupported traverses of 3 to 5 miles showed larger errors than did the adjusted elevations on loops, the probable error and maximum error being about 10 and 52 cm respectively.

CONSTRUCTION OF THE HYDROSTATIC LEVEL

The basic principle of the hydrostatic level as stated above is simple. Complications arise, however, in achieving the above accuracy using a commercially available manometer and meeting the specifications on range and sensitivity of the level. The pressure gauge used is a precision dial manometer manufactured by Wallace and Tiernan Products, Inc. As recalibrated in the hydrostatic level, the range is from plus to minus 10 meters and the least count is 2 centimeters. The readings are made to the nearest centimeter.

A schematic diagram of the hydrostatic level is shown in Figure 1. The hatchured area represents the water-filled system which is hermetically sealed. From right to left the water system extends from the manometer capsule (linked to the pointer of the dial manometer) through a short plastic tube to the brass zeroing chamber, and thence through line valve *1* to a saran tube which may be several hundred or even a thousand feet long. The other end of this tube is connected to the brass reservoir chamber below an unstretched rubber diaphragm supporting the float *4* visible through the lucite window *13*. Tap or drinking water is used to fill the system.

The reservoir operator maintains the position of the float *4* opposite an index mark on the lucite window *13* by an occasional adjustment of reservoir knob *5*. This knob acts through a screw on a bellows to change the volume and the height of the water in the reservoir chamber. During a reading the reservoir and manometer ends of the instrument are held in a vertical position as indicated by level bubbles. The manometer operator opens line valve *1* and reads the manometer to the nearest centimeter. This reading is the indicated elevation of the manometer end with respect to the reservoir end.

After a reading and before moving the level along a traverse, line valve *1* is closed to prevent pressure surges in the tubing from affecting the sensitive manometer capsule. In addition, the manometer pointer is returned to approximately zero by means of the zero adjustment knob *2*. This knob acts through a screw on a bellows to change the volume of water in the zeroing chamber, and hence the pressure in the water system to the right of line valve *1*. The manometer is zeroed immediately after each reading so that the position of the sensitive capsule is fixed except for the relatively short intervals of time required for each reading. This zeroing procedure minimizes errors due to mechanical hysteresis exhibited by the capsule and pointer linkage.

The manometer is normally sensitive to temperature change which affects

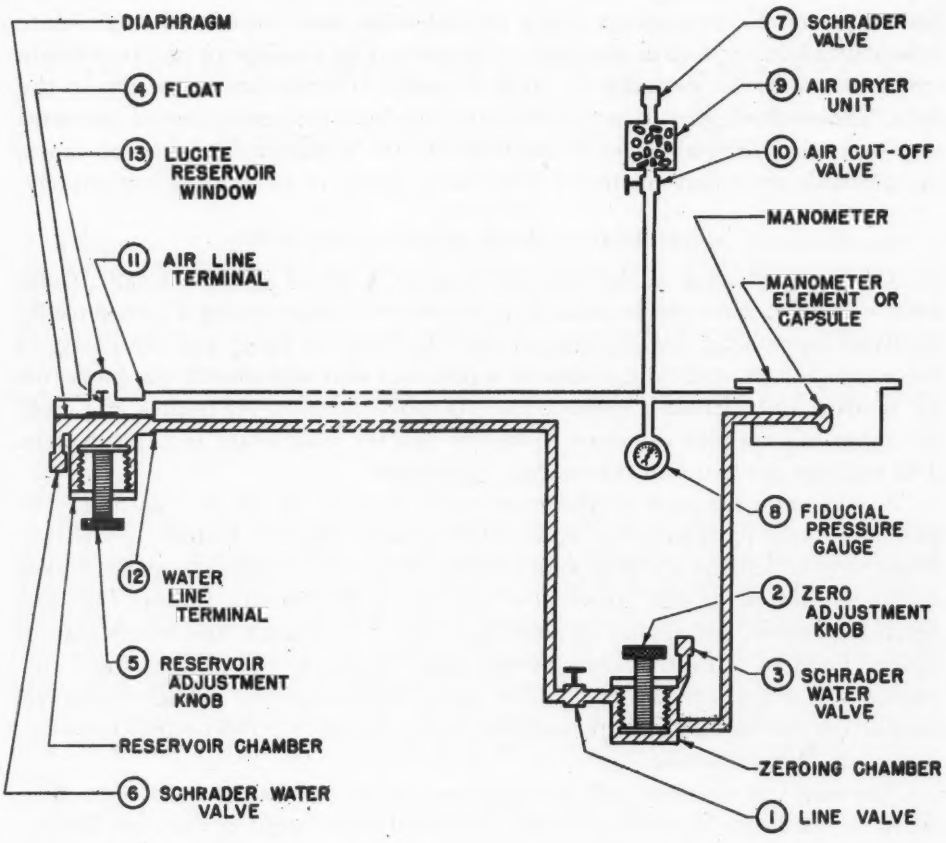

FIG. 1. Schematic diagram of the hydrostatic level.

both its zero and amplification. The zero shift with temperature is reduced to a centimeter or so by affixing a dissimilar metal strip to the movement in such a manner as to provide automatic differential thermal compensation. The amplification change of the manometer with temperature is fortunately compensated to a considerable degree by the density change of the water with temperature.

The unhatchured area in the diagram of Figure 1 represents the air-filled system which is hermetically sealed. From right to left the air system extends from the manometer case through a second saran tube to the reservoir chamber above

the rubber diaphragm. Air at about 15 pounds per square inch above atmospheric pressure is used. This fiducial pressure maintains the pressure throughout the water system at least as high as atmospheric pressure for elevation differences between the two ends up to 10 meters. The fiducial pressure prevents the formation of gas bubbles in the water system which would otherwise form for relatively small elevation differences between the two ends of the instrument.

The saran tubing used during the field tests was some 250 to 300 feet in length by 3/16 inch over-all diameter by 0.045 inch wall thickness. It is probable that water and air equilibrium would be reached in a satisfactorily short time for this size tubing in lengths up to 500 feet. For lengths of 1,200 feet, saran

FIG. 2. Hydrostatic level. The manometer is shown on the left, the reservoir on the right.

tubing 5/16 inch over-all diameter by 0.062 inch wall thickness was found satisfactory. Extra lengths of tubing can be inserted using a flaring tool and brass unions. This tubing tends to become somewhat brittle at temperatures below about 45° F., and of course the water-filled instrument can not be used in subfreezing temperatures. For use at low temperatures it would be necessary to use a different material for the tubing and to employ a liquid which would not freeze at the temperature encountered.

The picture of the hydrostatic level in Figure 2 shows the manometer end on the left, the reservoir end on the right. The total weight is 37 pounds, the manometer end weighing 22 pounds, the reservoir 7 pounds, and 300 feet of tubing with water weighing 8 pounds. In soft ground the curved bottom surface of the manometer staff makes a depression into which the similarly curved end of the reservoir staff is subsequently placed. In operations on hard rock, chalk or other marks are left by the manometer operator for the proper subsequent positioning of the reservoir. The instrument was calibrated at nearly constant temperature by a series of readings on a measured staircase. The direct-reading dial was prepared on photo-sensitized aluminum and checked on the staircase by a subsequent series of readings.

TEST CONDITIONS

For the purpose of testing the accuracy and general performance of the hydrostatic level, about 73 miles of traverse were run, mostly through brush and over rather rocky terrain simulating certain jungle conditions. Closed loops 3 to 5 miles long having topographic relief up to 55 meters were run. The extreme readings of the instrument were plus 9.82 and minus 9.49 meters, and about 10 per cent of the readings exceeded 5 meters, so that nearly the entire range of the instrument was tested. With tubing about 300 feet long, 1,579 readings were made.

The zero was adjusted by changing the length of the reservoir staff at the beginning of the test and was never subsequently adjusted. Tap water was used and was not changed in the manometer capsule during the test. The temperatures mentioned below are readings of a mercury in glass thermometer mounted inside the manometer case. They are not the ambient air temperatures but are rather the temperatures of the manometer element. The extremes noted throughout the test were 14° and 34°C. The temperature at which the instrument was calibrated was about 23°C.

It was desired to ascertain in the test the overall accuracy of elevation surveying with the hydrostatic level. Consequently, the elevations of a series of bench marks spaced about ½ mile apart were carefully measured with an optical level, and these elevations were taken as the true elevations of the bench marks. Traverses including these bench marks were run with the hydrostatic level, and the differences between the hydrostatic and optical elevations of the bench marks were considered errors by the hydrostatic level.

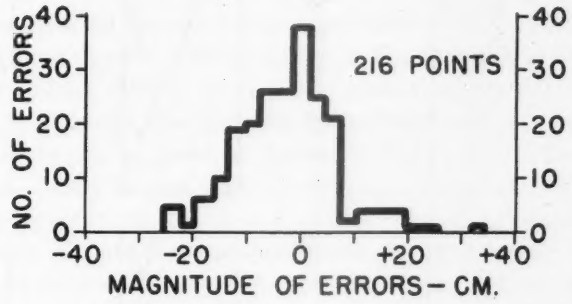

FIG. 3. Distribution of hydrostatic level errors at bench marks after proration of closure errors.

RESULTS OF ACCURACY TESTS

The closure errors on 3 to 5 mile loops were of the order of one meter. These rather large closure errors were primarily accumulated systematic errors such as would be expected from instrumental variations with changes in ambient temperature. Such errors are greatly reduced by the customary practice of prorating the closure errors, and the distribution of errors at 216 bench marks after such proration is shown in Figure 3. The probable error was about 6 cm and the maximum error found was 33 cm.

The loop data were also analyzed as if obtained on unclosed, unsupported traverses. In this case it was found desirable to apply a simple temperature correction which was determined empirically. The correction in centimeters to the elevation difference between the first and the N-th hydrostatic level station was found to be

$$C_N = 0.16\, N(23.5 - T)$$

where T denotes the average of the two extreme temperatures in degrees Centigrade observed during each day's work. The distribution of errors at 216 bench marks after such temperature correction is shown in Figure 4. In this case, indicative of accuracy on unsupported traverses of 3 to 5 miles, the probable error was about 10 cm and the maximum error found was 52 cm.

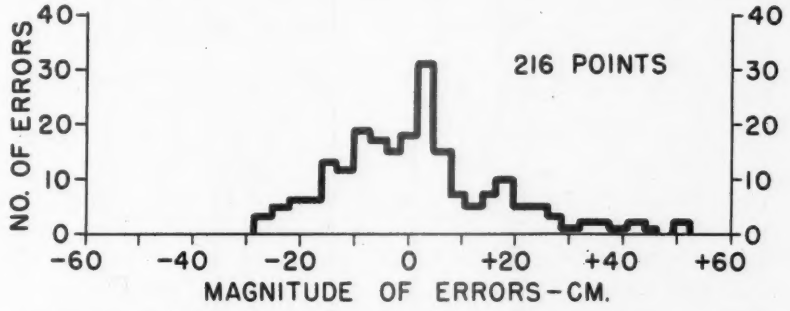

FIG. 4. Distribution of hydrostatic level errors at bench marks after temperature correction.

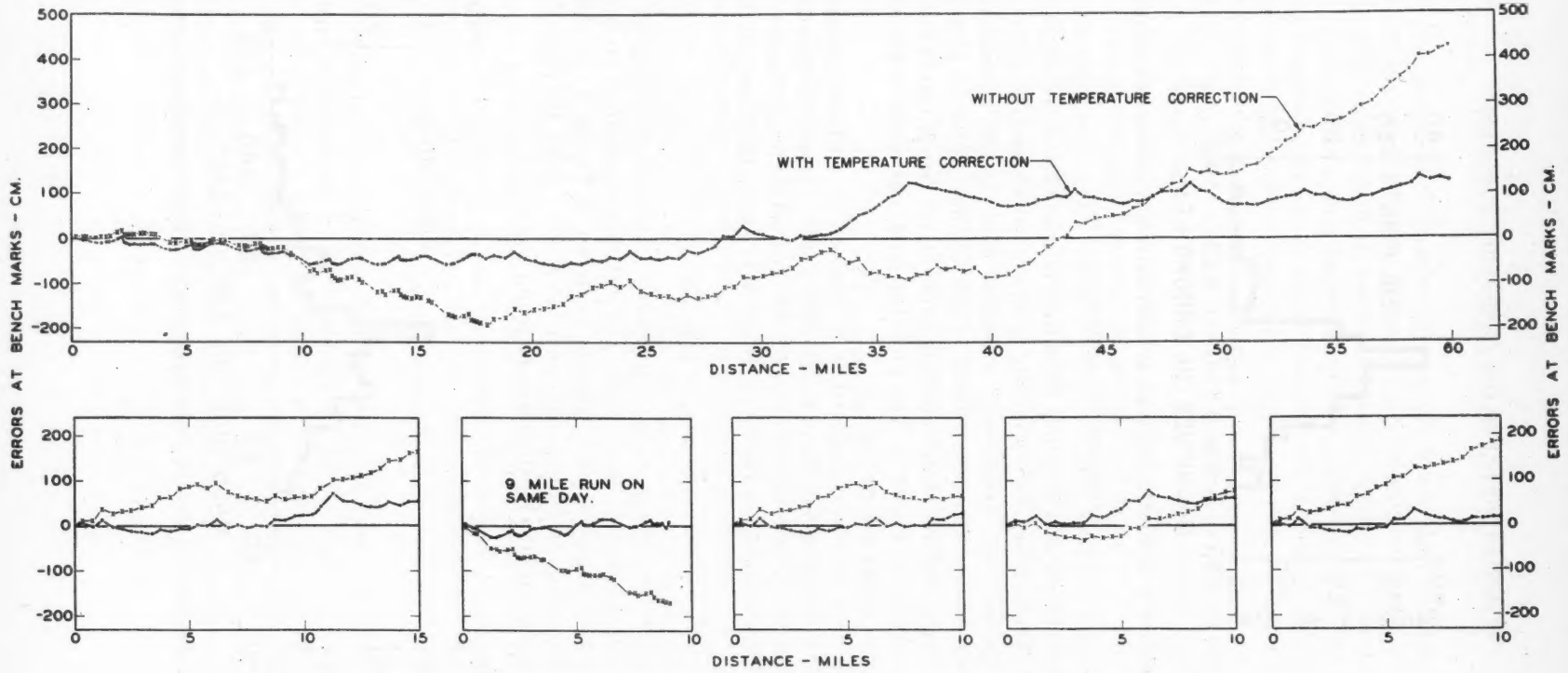
WITHOUT TEMPERATURE CORRECTION
WITH TEMPERATURE CORRECTION
ERRORS AT BENCH MARKS - CM.
DISTANCE - MILES
9 MILE RUN ON SAME DAY.

FIG. 5. Hydrostatic level errors at bench marks versus distance (with and without temperature correction).

Longer unsupported traverses were simulated from the data by joining the results from several days of work end to end. The errors at bench marks plotted versus distance along several synthetic traverses are shown in Figure 5. The crosses joined by the light line show the errors found without benefit of temperature correction; the circles joined by the heavy line show the errors with temperature correction. On the longest synthetic traverse of 60 miles, the errors with and without temperature correction do not exceed 138 and 426 cm respectively.

The accuracy of elevation surveying with the hydrostatic level as found in this test appears to be sufficient for some types of geophysical work, particularly on closed loops.

RESULTS OF GENERAL PERFORMANCE TESTS

The durability of the saran tubing used for the air and water lines was tested in part by dragging parallel and twisted pair forms behind a vehicle. Parallel pairs were found to last much longer than twisted pairs, being still in operating condition after 90 miles of dragging. After the parallel form was adopted, the tubing showed little wear after 48 miles of traverse.

The average speed of traverse was about 1 mile per hour at the rugged, brushy test site, and from 1½ to 2 miles per hour on roads.

The various valves, controls, and sealed chambers gave no trouble during the test. During transportation on a truck and when not in use the instrument was kept in a fitted case. Dropping the manometer end to the ground may or may not bend the pointer which is quite thin at its extremity (for fine reading). The linkage system between the capsule and the pointer appears more rugged than the pointer itself. If the manometer should be seriously damaged, a spare is provided for use until the original can be repaired and checked, or until another manometer can be supplied.

The accuracy and general performance of the hydrostatic level appear sufficient for exploration use, and it is hoped that a material saving in surveying costs in difficult areas can be effected.

GEOPHYSICAL EVALUATION OF THE MARFA BASIN OF TEXAS*

JOHN H. WILSON†

ABSTRACT

Information on past geophysical investigations of the Marfa Basin of Texas is given. Special problems are involved in the application of geophysical methods.

INTRODUCTION

The Marfa Basin presents a very difficult exploration problem since lava flows laid down after the larger structural movements may conceal the surface geological features and because these same flows and their erosional products may greatly interfere with the use of geophysical methods.

The challenge of relatively unexplored basins cannot be ignored by the geologist and geophysicist and much experimental work will take place. A summary of past geophysical work is given below. This list is probably not correct in detail since in an isolated area such as this, some surveys may have been done without notice.

TABLE 1

TABULATION OF GEOPHYSICAL SURVEYS

Year	Company	Method	Area
1943	Atlantic	Gravity Meter	Western Brewster County
1943	Phillips	Gravity Meter	Western Brewster County
1943	Sinclair	Magnetometer	Western Brewster County
1944	Humble	Gravity Meter	Presidio, Jeff Davis and Brewster Cos.
1947	West	Gravity Meter	Presidio Area
1949	Fairchild	Reconnaissance airborne magnetometer profile	North end of Marfa Basin
1947–1950	West	Seismograph	Presidio Area
1950	Cities Service	Seismograph	Brite Ranch, Presidio County

MAGNETIC METHODS

The magnetic properties of collected specimens from the area, as determined by Frost Geophysical Company, are shown in Table 2 below.

It is interesting to note that in every case samples out of the well were more magnetic than surface outcrops of the same formations. The sample of Shafter limestone from near the Shafter mining district, although apparently normal, has abnormal magnetic properties and this raises the question if magnetic surveys of the limestone areas might indicate mineralization.

* Delivered at the Joint Regional Exploration Meeting, Ft. Worth, Texas, December 1, 1950. Manuscript received by the Editor December 4, 1950.

† Ft. Worth, Texas.

TABLE 2

MAGNETIC PROPERTIES OF ROCKS

Description of sample (arranged in geologic time sequence)	Density	Volume Susceptibility $\times 10^6$
Tascotal (Rawls?) basalt. 12 miles from Marfa on Presidio highway in Presidio County	2.655	2,305
Tascotal Tuff on Alamito Creek. 20 miles south of Marfa in Presidio County.	2.113	272.7
Mitchell Mesa Rhyolite. 1.4 miles east of Jordan Gap in Presidio County.	2.3076	23.2
Duff Tuff in Paradise Valley. 10 miles easterly from Jordan Gap in Brewster County.	2.1609	106.3
Duff Tuff at depth of 670–680 in Argo No. 1 Mitchell-State Presidio County.	2.0989	258.6
Cottonwood Springs Basalt at Whirlwind Springs in Brewster County.	2.717	1,395.0
Cottonwood Springs Basalt (?) at depth 1,620–30 in Argo #1 Mitchell-State, Presidio County.	2.6388	3,361
Crossen Trachyte from Crossen Mesa. 30 miles south of Alpine in Brewster County.	2.5745	234.8
Crossen Trachyte (?) at depth 2,140–50 in Argo #1 Mitchell-State, Presidio County.	2.501	1,110
Pruett Tuff from near Whirlwind Springs, Brewster County.	2.1293	81.4
Pruett Tuff at depth 2,750–60 in Argo No. 1 Mitchell-State, Presidio County.	2.304	415
Boquillas Flags. 33 miles south of Alpine in Brewster County.		Slightly diamagnetic
Cretaceous at depth 3,110–3,120 in Argo No. 1 Mitchell-State, Presidio County.	2.324	34.7
Shafter limestone (possibly slightly mineralized) at town of Shafter, Presidio County.	2.3999	640.6
Permian lime at depth 3,970–80 in Argo No. 1 Mitchell-State, Presidio County.	2.4954	21.3
Upper Wolfcamp at depth 6,040–50 in Argo No. 1 Mitchell-State, Presidio County.	2.6318	45.9
Lower Wolfcamp at depth of 7,040–50 in Argo No. 1 Mitchell-State, Presidio County.	2.6385	31.3
Cisco zone at depth of 7,650–60 in Argo No. 1 Mitchell-State.	2.6213	45.3
Canyon zone at depth 8,605–10 in Argo No. 1 Mitchell-State.	2.5871	28.7
Strawn zone at depth 8,945–50 in Argo No. 1 Mitchell-State.	2.6487	29.4
Strawn or older zone at depth 9,435–40 in Argo No. 1 Mitchell-State.	2.6626	32.2

Since many of the volcanic rocks contain up to 10 per cent to 15 per cent magnetite, it is to be expected that there will be many polarized anomalies. The limits of these volcanic rocks could be easily determined by magnetic methods but they are also usually well exposed. An airborne magnetometer survey would quickly indicate the areas of volcanic rocks and it would be easy to calculate the effects of the flows from the magnetic surveys. Preliminary reconnaissance airborne magnetometer lines across the Davis Mountains and Marathon area are said to allow the differentiation of extrusive and intrusive volcanic rocks. It is doubtful if the minor anomalies associated with local structural features could be adequately separated from the effects of a varied igneous system of flows and intrusions.

The areas of Pre-Tertiary sedimentary exposures would offer no special problems where free from igneous float and in some cases magnetic work would help to distinguish between normal structures and those of laccolithic origin. However,

it should be remembered that not all intrusive igneous rocks are more magnetic than the sedimentary rocks surrounding them. Some laccolithic structures farther south in Mexico show no appreciable magnetic anomalies.

In the flats containing sediments of Tertiary and younger age, there are usually fragments of igneous rocks which are highly magnetic. In Figure 1 will be seen profiles with stations ten feet apart.

Profile A is a survey in the alluvial flat just east of Crossen Mesa, 29.4 miles south of Alpine on Terlingua road in Brewster County where the rocks near the

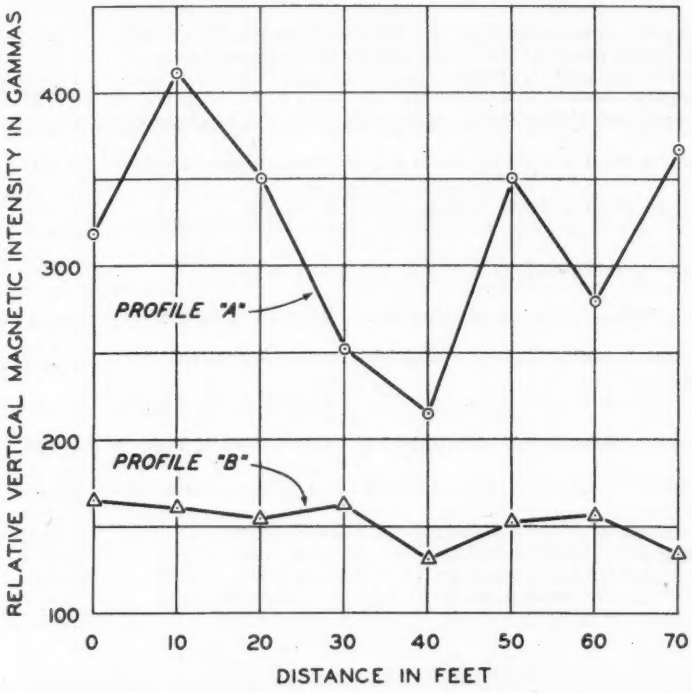

FIG. 1. Marfa Basin magnetic profiles.

surface are gravels and boulders up to two feet in diameter of trachyte, basalt, and other rocks. The age of alluvial deposits was probably Pleistocene to Recent. It will be noted that there are large variations in short distances. Effects of the individual shallow boulders would be largely eliminated in an airborne magnetic survey taken some distance above the ground.

Profile B is a survey on the Marfa plain on the Presidio highway, in Presidio County, 3.4 miles south of Marfa. It is located on basin fill possibly as old as Pliocene. It will be noted that the amplitudes of the variations are only about one tenth of those in Profile A which may be explained by the older age of the sediments, the smaller size of the boulders and possibly also the different character of the boulders.

In general, magnetic methods will probably be used more in the solution of special geological problems than for indication of local structure.

GRAVITATIONAL METHODS

The density of collected samples of rocks as determined by the Frost Geophysical Company is given in Table 2.

It will be noted that some of the igneous rocks are very dense so that buried or intrusive masses of these rocks will have a very decided gravitational effect.

Elevation corrections for gravity surveys will be a difficult problem because some topographic features may be largely composed of a light tuff while others may be capped by a dense basalt or trachyte.

It may be very difficult to pick out local structural effects from gravitational surveys where there are so many non-structural effects such as topography, subsurface distribution of igneous rocks, and variable surface rocks. However, with a knowledge of the geology of the area and the location of surface features causing anomalies, it may well be that a gravity survey would reveal information on the outline of the basin which is at present imperfectly known.

SEISMIC METHODS

There is very little public information on subsurface velocities. No velocity surveys are known to have been made in the basin but very probably some velocities have been calculated from differential reflection times. The exposed Cretaceous and older rocks appear indurated and velocities may be relatively high for the age and composition of the formations as is not unusual in narrow basins near igneous activity.

There are possibilities of reflecting horizons in the Tertiary flows and tuffs but these would be of questionable value for Pre-Tertiary structural features. In the deeper part of the basin, the contact of the Upper Cretaceous shales with limestones may give good reflections and there are formation changes in the Permian that may also give reflections. In part of the basin, the Pennsylvanian is largely shale and sand. Larger sand bodies and reefs in this zone should give reflections. The contact of the Pennsylvanian argillaceous series with underlying limestones should also be a good reflecting horizon.

In areas where high velocity lavas or high velocity limestones are on the surface, it is doubtful if the reflection or the refraction method would be very satisfactory. In such areas, it may be possible to do limited reconnaissance along alluvial valleys or where the softer tuffs are exposed. In most valleys between flows, the large boulders would present very strong obstacles to the drilling of shot holes.

The most favorable areas for seismograph work appear to be the large plains in the northern and western portions of the area, particularly where Upper Cretaceous shales are exposed or finer grained alluvial deposits lie directly on these

shales. In such areas, the topography, as well as the geological conditions, are favorable for both reflection and refraction methods.

Scout information on seismograph surveys has given a limited amount of information. Hole depth has been up to 300 feet and this depth has not always reached the water table. Hole drilling has been difficult on account of boulders and in several places production has been one hole or less per rig. Both rotary drills and spudders have been used. Weathering is quite variable as would be expected. Reflections, in general, are poor with some difficulty reported in carrying continuous horizons. Much more work will be done before the workability of the area is determined. Very probably there will be some local areas with good reflections and many others where reflections are not obtained or are not adequate for accurate structural determination.

RADIOACTIVE METHODS

There have been unconfirmed rumors of radioactive minerals in the Marfa basin. Use of an airborne geiger counter in conjunction with an airborne magnetometer might be worthwhile.

TREND OF GEOPHYSICAL WORK

It is believed a comprehensive exploration program for the basin would involve the following steps.

1. Aerial mapping.
2. Geological mapping, using aerial photographs.
3. Airborne magnetometer (with radioactive survey).
4. Gravity meter survey.
5. Seismic surveys of areas most favorable to the method to cover anomalies indicated by previous methods.

ACKNOWLEDGMENTS

Assistance in the preparation of this report has been given by a number of geophysicists but special thanks are due to Dr. Joseph A. Sharpe of the Frost Geophysical Corporation for determination of densities and magnetic properties of rock samples, to Mr. James L. Morris for field assistance, and to Dr. W. A. Waldschmidt of the Argo Oil Corporation for well samples.

DEEP BASEMENT REFLECTIONS IN BIG HORN COUNTY, MONTANA*

ARNE JUNGER†

ABSTRACT

During a seismic survey in Big Horn County, Montana, a number of deep reflections from 7.0 to 8.5 seconds were observed. The reflecting surfaces are relatively flat as shown by the small step-outs. It is demonstrated that these reflections cannot be multiples and that they therefore must come from inside the basement at depth of 18 to 21 km. The nature of the reflecting surfaces cannot be determined from available data, but it is pointed out that they fall in the depth range generally stated for the depth of the granitic layer.

During experimental seismic work by Shell Oil Company in an area covered by clinker beds in Big Horn County, Montana, near the Wyoming border, it was found that an ordinary sized charge of approximately 25 pounds would set up a low frequency surface disturbance which lasted for an unusually long time. To see how long this disturbance would last the observer kept the camera running for more than ten seconds. The resulting record is shown in Figure 1. A distinct reflection will be noticed at 8.5 seconds, but otherwise the record shows nothing but low frequency surface disturbance characteristic of clinker areas. The duplication of this reflection on a repeat shot eliminates the possibility that it is the accidental recording of a shot from another crew or from a quarry blast.

No systematic experimental work was done to determine the origin of this reflection, but during routine operations in adjoining areas, where there are no clinkers, the camera was at several occasions kept running to a time of approximately ten seconds. At no time was another outstanding reflection observed as late as 8.5 seconds, but in many cases distinct reflections were observed as late as 7.0 to 7.5 seconds. Examples of these records are shown in Figures 2 and 3. Figures 4 and 5 show a deep reflection at 7.5 seconds from an area approximately forty miles from the first area. These two records are from the same shot point but with the instrument lines at right angle to each other. Following the reflection from the top of the basement, which appears distinctly on most records from these two areas, energy with a vague tendency to line up is shown to the end of the record. Besides this rather confused energy a few distinct reflections are shown, the better ones often occurring at a time of 7.0 to 7.5 seconds. These reflections can always be duplicated by repeat shots, but otherwise they show very little consistency. They vary greatly in time and appearance from place to place and show very little continuity where adjoining long records are available. It would be tempting to correlate the very good reflection shown on Figure 3 with

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† Shell Oil Co., Inc., Casper, Wyoming.

the equally good reflection shown on Figures 4 and 5 approximately forty miles away, but records from shots close to both of these do not substantiate such a correlation. The reflections on Figures 2 and 3, approximately one mile apart, show a different character. Figure 6 shows three consecutive records spaced 1,100 feet apart. Record "A" is the same as shown in Figure 3 with an outstanding reflection at 7.2 seconds. The adjoining record "B" shows only a faint reflection at this time but shows a somewhat better reflection at 7.0 seconds, which does not appear on "A." The third record "C" shows neither of these two reflections,

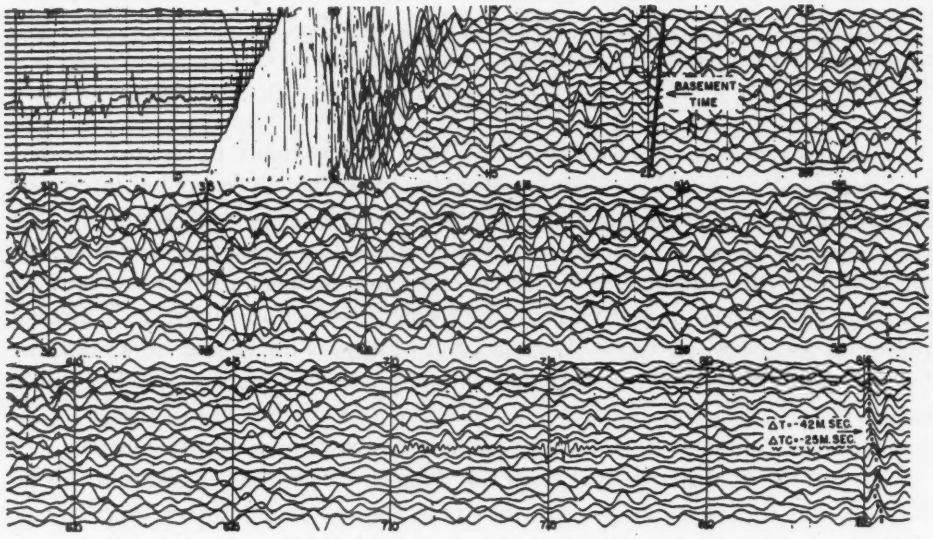

FIG. 1. Clinker record with reflection at 8.5 seconds.

but in the time interval from 6.5 to 7.0 seconds it shows several reflections with a step-out of 25 to 40 milliseconds.

One outstanding feature of these late reflections is that the step-out is quite small, generally less than 10 milliseconds for an instrument spread of 2,200 feet. The large step-out shown on record "C," Figure 6, is the one outstanding exception noticed. The reflection on Figure 1 has a step-out of 25 milliseconds when corrected for weathering and topography, but this value is in considerable doubt because of very rough topography and clinker beds. Figures 4 and 5 represent the only example of records obtained in different directions from the same shot point. Here the deep reflection shows a very small step-out in both directions, thus proving that its path is vertical.

These late reflections pose some rather puzzling questions, the most obvious of which is: where do they come from?

After the elimination of refracted reflections by virtue of the small step-outs, there appear to be only two possible explanations for such late reflected energy, namely:

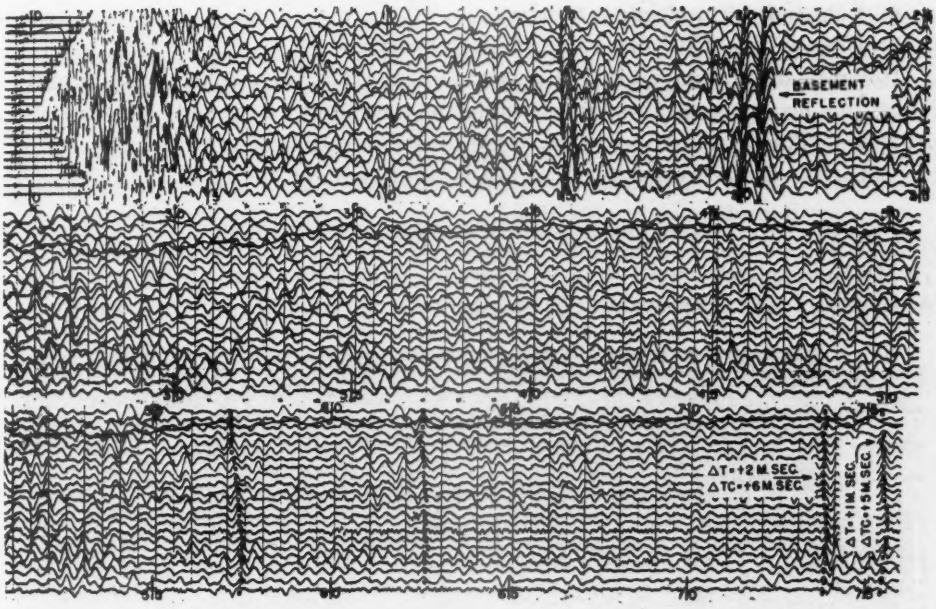

FIG. 2. Record with reflection band at 7.4 to 7.5 seconds.

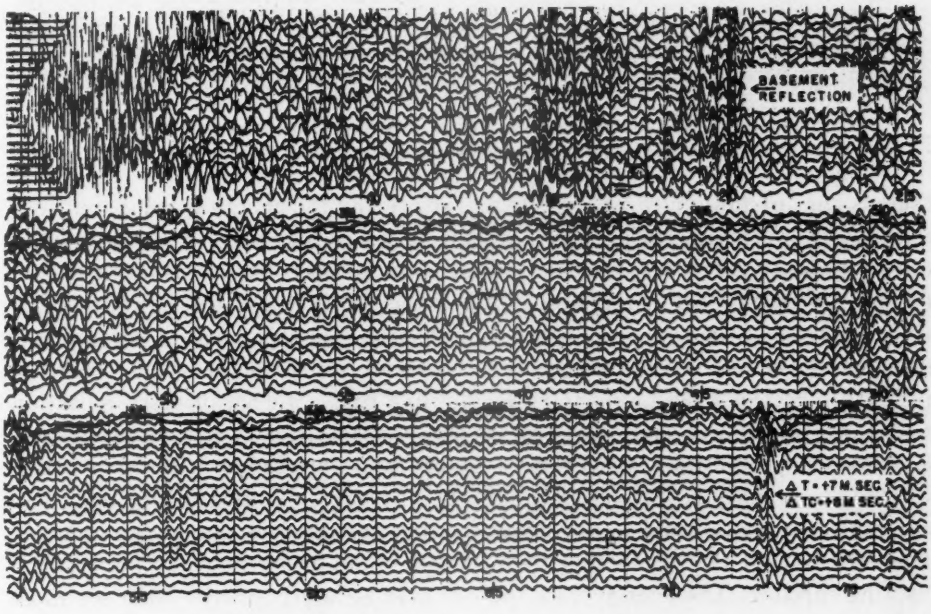

FIG. 3. Record with strong reflection at 7.2 seconds.

1) Energy from multiple reflections.
2) Energy reflected from inside the basement.

It can readily be shown that it is very unlikely that these reflections are multiples thus leaving reflections from inside the basement as the only possible explanation. This explanation raises some very interesting questions concerning the nature of the reflecting surfaces inside the basement.

ARGUMENT AGAINST MULTIPLE REFLECTIONS

Multiple reflections have been observed numerous times (Ellsworth 1948, Waterman 1948). The examples published are all from the simple case where

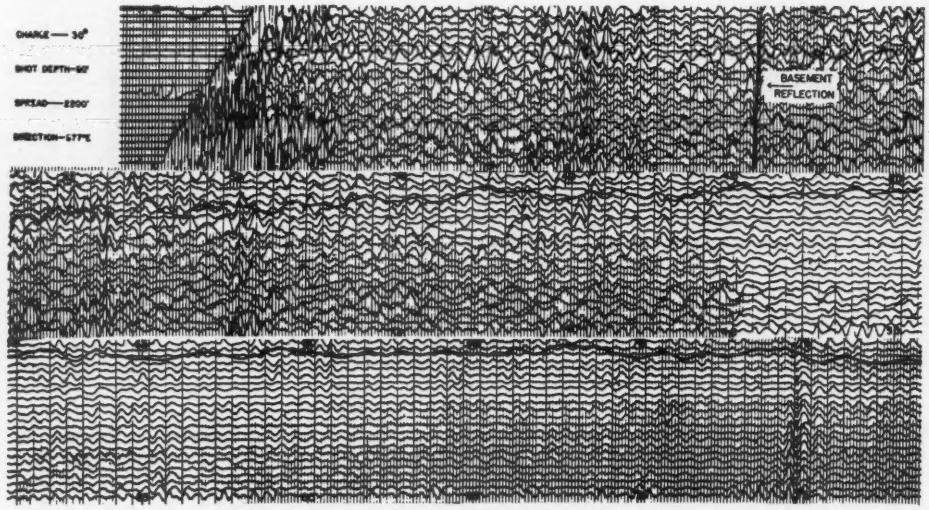

FIG. 4. Record with strong reflection at 7.5 seconds from area 40 miles from those shown in Figures 1, 2, and 3.

there is one outstanding strong reflecting surface and the energy is being multiply reflected between this surface and the base of the weathering (or the surface of the ground). As the reflected energy impinges on the base of the weathering the reflection here would act as a repeat shot and the whole record will be repeated at time intervals of the time for the strong reflection (Johnson 1948). If several approximately equally strong reflecting surfaces are involved the whole record of primary reflections will be repeated at multiple times of each primary reflection with the result that the part of the record past the last primary reflection will show a great many multiples very closely spaced and interfering with each other. Should the primary reflections have slightly different step-outs the interference of the multiples would tend to obliterate the line-ups. Besides the energy reflected from the base of the weathering there should be multiples reflected between reflecting surfaces. The energy from these should be much smaller than for those reflected at the base of the weathering because of the smaller reflecting coefficients,

but the aggregate effect may be sufficient to add to the confusion of the latter part of the record. It is an observed fact, even under the most ideal conditions, shat the reflections become less distinct for each time they are reflected (Johnson 1948). The records of Figures 2 and 3 show two distinct reflection bands at 1.5 and 2.0 seconds, respectively, but there are no strong energy bands at multiple times of these reflections. Except for the good reflections between 7.0 and 7.5 seconds these records show, after the basement reflection, continuous energy with a vague tendency to line up, and poor line-ups which rarely can be traced across the whole record. This type of record conforms well with what may be expected from multiple reflections where several reflecting surfaces are involved, but the

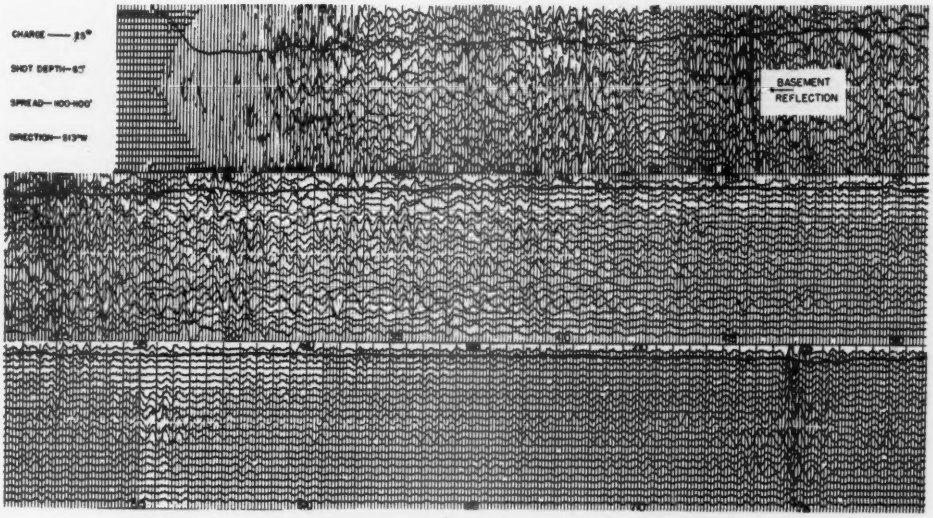

FIG. 5. Record from same shot point as Figure 4 but with instrument spread at right angles to this.

good reflections between 7.0 and 7.5 seconds do not fall into this category. That several multiple reflections accidentally should arrive in phase to give a strong narrow reflection band is beyond the realm of probability, and it must therefore be concluded that these reflections are not multiples.

ENERGY REFLECTED INSIDE THE BASEMENT

At present the only logical explanation for these late reflections appears to be that they come from inside the basement. The erratic appearance and the observed discontinuity would at first consideration argue against this explanation, as one would expect reflecting surfaces at such great depths to be continuous over fairly large areas. But the observed facts call for an explanation of discontinuous reflecting surfaces inside the basement rather than for another source of the reflections.

As these reflections come from inside the basement it is of interest to speculate on the nature of the reflecting surfaces. In the Big Horn Mountains approximately 25 miles to the south the basement consists of pre-Cambrian schists, gneises, and granitic intrusions which condition undoubtedly exists to great depth. With such a heterogeneous basement it is only natural to expect reflections from inside the basement. These are actually observed quite often, as on the records from Figures 4 and 5 which show strong reflections below the basement to a time of 3.0 seconds. The peculiarity of the reflections under discussion is their

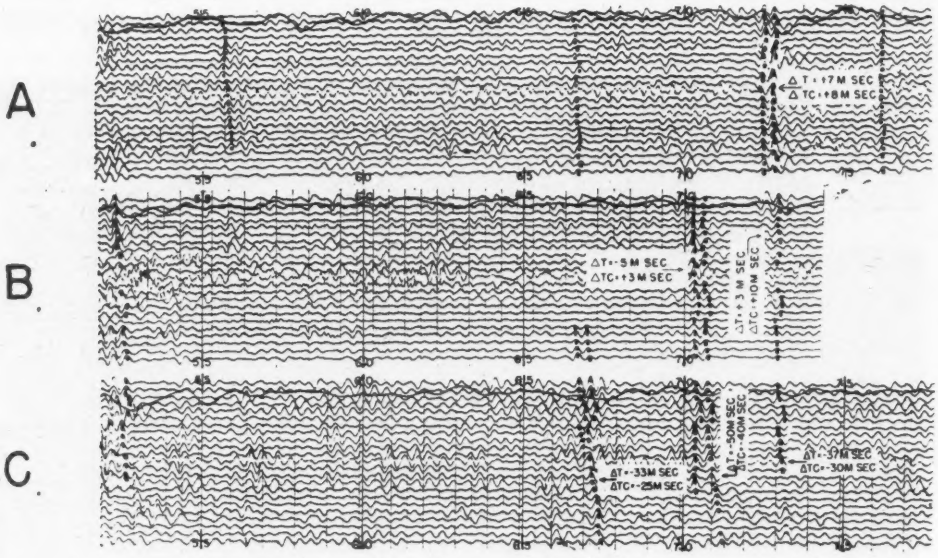

FIG. 6. Three consecutive records showing discontinuity of deep reflections. Record A same as the one shown in Figure 3.

great time and general concentration inside a rather narrow time limit. The reflection on the record shown in Figure 3 occurs 5.2 seconds later than the basement reflection. Assuming a basement velocity of 18,000 feet per second (observed value near the top of the basement) a depth of 46,800 feet (approximately 9 miles or 14 km) below the top of the basement is obtained, and as the basement is approximately 12,000 feet below the surface, the total depth is 58,800 feet (approximately 11 miles or 18 km). On the record shown in Figure 1 no basement reflection is shown, but assuming the same depth as for the record from Figure 3, which certainly would be correct inside a few hundred feet, a depth to the reflecting surface of 58,500 feet (approximately 11 miles or 18 km) below the top of the basement is obtained, and 70,500 feet (approximately 13½ miles or 21 km) below the surface. These are minimum values as the basement velocity increases with depth.

Refraction studies of local earthquakes and large blasts in California and

northern Europe give a thickness of 10 to 25 km for the granitic layer (Byerly 1939, 1946, Willmore 1949). It is interesting to notice that the depths given above fall inside this range. It may be tempting to conclude, therefore, that these reflections come from the base of the granitic layer. However, the data hardly warrant such a conclusion if the base of the granitic layer is conceived as a sharp discontinuity. The records shown on Figures 1 and 3 are from shots only one mile apart, and with the instrument lines normal to each other. The depths of the two reflections differ by approximately two miles, and as both records indicate comparatively flat reflecting surfaces they can hardly be from the same discontinuity. If, on the other hand, the base of the granitic layer is a transition zone of heterogeneous material then the observed deep reflections could possibly be associated with this.

CONCLUSIONS

The only satisfactory explanation to these late reflections is that they are reflected within the earth's crust. The very meager data available show discontinuous reflections from a relatively narrow depth zone from approximately 18 to 21 km. This is inside the depth range generally given for the base of the granitic layer, and, consequently, these reflections could be of great scientific interest.

It is hoped that the presentation of these records will stimulate interest in others to look for similar late reflections, and that ultimately sufficient systematic data will be gathered to give a better answer to their origin, and possibly shed some light on the very interesting problem concerning the internal structure of the earth's crust.

ACKNOWLEDGMENT

The writer wishes to express his appreciation to Mr. Jesse Parker for bringing these deep reflections to his attention, to Dr. M. King Hubbert and Dr. Perry Byerly for helpful information and to Shell Oil Company for permission to publish this information.

BIBLIOGRAPHY

Perry Byerly, "Near Earthquakes in Central California," *Bull. Seismological Society of America, XXIX* (1939), 427–462.

———, "The Seismic Waves from the Port Chicago Explosion," *Bull. Seismological Society of America, XXXVI* (1946), 331–348.

T. P. Ellsworth, "Multiple Reflections," *Geophysics, XIII* (1948), 1–18.

Curtis H. Johnson, "Remarks Regarding Multiple Reflections," *Geophysics, XIII* (1948), 19–26.

J. C. Waterman, "Multiple Reflection Evidence," *Geophysics, XIII* (1948), 41–44.

W. B. Willmore, "Seismic Experiments on the North German Explosions, 1946–1947," *Philosophical Transactions of the Royal Society of London, Series A, No. 843, Vol. 242* (1949), 123–151.

A SEISMIC REFLECTION QUALITY MAP OF THE UNITED STATES*

PAUL L. LYONS†

ABSTRACT

A reflection-quality map of the United States has been prepared by a subcommittee of the Program and Arrangements Committee for 1950–51. The map designates as good, fair, or poor to NG all sedimentary areas of the United States in respect to reflection quality in seismic explorations. The map may be used in the planning of seismograph operations. Reflection quality is a function of many factors.

INTRODUCTION

The chairman of the program committee for the year 1950–51, Dr. Sigmund Hammer, endorsed the preparation of a seismic reflection-quality map of the United States. The map was prepared by a subcommittee of the program committee consisting of Paul L. Lyons, chairman, Glen Bader, O. K. Fuller, Jr., H. M. Thralls, and Wm. M. Erdahl. The subcommittee proposes to the membership of the Society that regional maps of this type should be prepared periodically by research committees for publication in *Geophysics*.

THE REFLECTION QUALITY MAP

The reflection quality map here presented is drawn from all available data concerning reflection quality in all areas of the United States where sedimentary reflections may be obtained.

The reflection qualities are expressed in three groups. These are (1) good, (2) fair, and collectively (3) poor to no good. The classifications refer to the quality of records obtainable and do not express difficulties due to velocity change, etc. The simple criteria used to establish the grades are: (1) *Good* areas are those in which reflections are sufficiently clear and consistent so that records may be correlated, like electric logs, over fairly large areas with reasonable assurance. (2) *Fair* areas are those in which continuous profiling must be employed to assure proper correlation and to determine continuity of reflection horizons. (3) *Poor to NG* areas are those in which continuous profile reflection data must be employed, but which yield only phantom dip maps, or no results. It is understood, further, that these classifications refer to conventional seismic operations wherein shot holes and a moderate number of geophones are employed. It is recognized that use of special seismic techniques improves the quality of data in a great many areas.

On the map, the three classifications are indicated by various shadings. An

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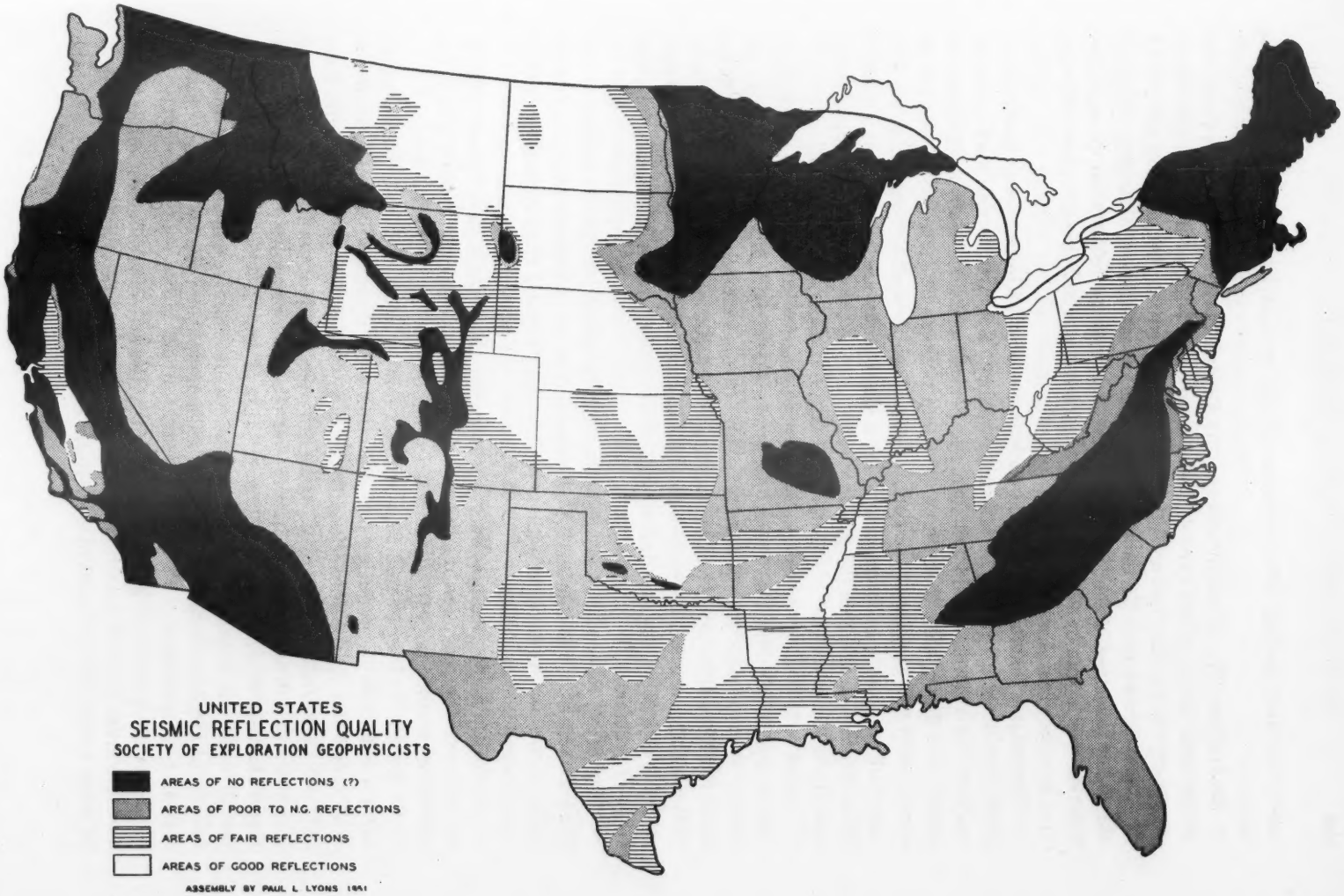
† The Carter Oil Company, Tulsa, Oklahoma.


UNITED STATES
SEISMIC REFLECTION QUALITY
SOCIETY OF EXPLORATION GEOPHYSICISTS
AREAS OF NO REFLECTIONS (?)
AREAS OF POOR TO N.G. REFLECTIONS
AREAS OF FAIR REFLECTIONS
AREAS OF GOOD REFLECTIONS
ASSEMBLY BY PAUL L LYONS 1951

additional dark shading refers to areas where it is unlikely that reflections may be obtained.

Of the possible reflection areas of the United States (which are 75 per cent of the total area), 55 per cent are designated as yielding poor to NG reflections, 28 per cent as yielding fair reflections, and 17 per cent as yielding good reflections.

These figures may be tempered with the observation that a great many of the poor reflection areas are extremely marginal as regards oil possibilities, whereas this is true to a lesser extent in the fair and good areas. A good reflection area is somewhat of a geological rarity.

The map is generalized. Within each area shown within a given classification, there may exist all ranges of reflection quality. Yet within each such area the majority of records should fall into the general classification shown. There is reason to believe, also, that the map should perhaps be more spotty and inconsistent with the geology of the country than here shown. The map is not a final map but is rather a progress report, for a great many areas have been classified by extrapolation in which the grading is extended on the basis of similar geological and surface conditions.

Areas of lava flows constitute the worst areas for reflections. An example of this is the Marfa Basin of Texas. Areas of near surface high velocity beds are usually areas of poor to NG reflections, and this is generally true of the Permian basins of the southwest. Areas of unusually thick glacial drift may or may not be poor reflection areas. The thick drift of Michigan makes the area of its occurrence an NG reflection area, but similar drift thicknesses in other areas are no barrier to good reflections.

In general, Paleozoic areas are better than Mesozoic, which are in turn better than Cenozoic. Consolidation or metamorphism of sediments up to a certain point seems to improve reflection quality, but beyond that reflection quality would seem to deteriorate.

There are many localities on the map where the geology may be seen clearly to influence the reflection quality. Conversely, there are also places where the geological reasons for variations in reflection quality are obscure.

In general, it may be said that complex folding and faulting of sediments are far less operative in producing bad reflection areas than are near surface effects. Unconformities in the subsurface, surprisingly enough, as a general rule have little effect on reflection quality. As an example, the Hunton limestone of Oklahoma has an unconformity at its top; yet that unconformity surface often produces excellent reflections. In the "good" area of central Oklahoma reflections received from the Hunton and Pennsylvanian beds are responsible for the first successful application of the reflection seismograph in 1927 by the Geophysical Research Corporation.

There is some indication that areas where the rate of sedimentation has been slow are areas of good reflections. This statement may be true for the vast areas of good reflections in the Williston Basin of the Dakotas and Canada. On the

other hand, this may simply be a manifestation either of age and consolidation of sediments or of favorable surface conditions.

There does seem to be an optimum over-all velocity in the range 8,000 to 10,000 feet per second which favors good reflections. There is a tendency for the areas of lesser over-all velocity (to a given depth) to yield lower frequency reflections, and for areas of higher over-all velocity to yield higher frequency reflections. However, this statement has many exceptions and is true in only the most general way. In the matter of reflection frequency, the surface and near surface beds exercise the dominant effect on the records.

The reflection quality map portrays the battleground for reflection seismograph. The obtaining of usable records is of constant concern to all operating seismic parties, and this is true even in the good areas. It is of the greatest concern in the poor reflection areas, and there it requires the best of shooting techniques, the best of instruments, and the utmost in ingenuity to make operations yield results.

It is well, in planning seismic operations, to consider the quality of data expected. It has a great deal to do with the ultimate risks involved in drilling operations, and in the expectation of finding structural anomalies overlooked by the competition. For example, the calculated expenditure of large sums for seismic exploration in favorable oil areas where the reflections are poor should result in the finding of the greatest numbers of yet unknown prospects. In these areas the competitive "shooting" has been less due to the poor quality of reflections. In the past, operators have simply moved from these areas to better reflection areas, leaving a substantial crop of structures for the gleaners. Because of this, these poor areas have become the target for various new techniques designed to improve seismic data, and a great deal of research is being expended to find ways of getting satisfactory reflections in these areas. Since it is probable that at least some poor areas will continue to defy attempts to improve results, it may be seen that an entirely new method of locating either oil traps or oil is needed in these areas and will be sought.

The good areas offer a different sort of promise. There the obvious anomalies may be expected to have all been found with comparative ease by use of rapid seismic methods. The good quality of data in these areas, however, makes it possible to map intricate phases of sedimentary relationships not possible in areas of poorer data. The accurate data obtained permit the seismograph to map structures of low relief as well as some stratigraphic trap types of prospects.

The fair areas partake of some of the opportunities of both the good and poor areas. Here especially are included areas where competitive parties have either carelessly failed to get the maximum information obtainable, or have failed to use techniques which would assure them greater resolution of data.

In conclusion, the subcommittee hopes that the publication of this map will be the forerunner of more regional maps contributed to the general knowledge by geophysicists of this society. Comments and revisions of this map are solicited

with the expectation that a more accurate one may ultimately be drawn.

Thanks are extended to The Carter Oil Company, the Humble Oil and Refining Company, the Skelly Oil Company, and Seismograph Service Corporation for permission to publish the map, and to Mr. E. M. Whaley, of The Carter Oil Company, who drafted the final copy of the map.

In addition, especial thanks are extended to those members of the Society of Exploration Geophysicists who have contributed case histories to the various publications of the Society. These case histories were the greatest single source of information available on reflection quality.

ANNUAL SURVEY OF GEOPHYSICAL EDUCATION 1950–1951*

Submitted by JAMES B. MACELWANE, S.J.

The Standing Committee on Geophysical Education of the Society of Exploration Geophysicists was commissioned four years ago to make an annual survey of the status of geophysical education in the universities and colleges of the United States and Canada. The results of two successive annual surveys have been published in the official journal of the Society *Geophysics*. The first survey covered all the institutions of higher learning in the two countries. The second was more restricted. Reports were asked only of those universities and colleges which were known from the previous survey to be giving instruction in geophysics.

This year at informal conferences between the members of the committee it was decided that the time was again ripe for general coverage. Accordingly nearly one thousand questionnaires were sent with a covering letter to various officials and departments in 265 universities and colleges. The response was excellent. Replies were received from 254 institutions and most of these were very clear and complete. If some few were misinterpreted the chairman takes full responsibility for the mistakes. The details are presented in the appended tables.

A comparison of these tables with previous reports will show a steady growth. The number of fully constituted departments or institutes in the field of geophysics has increased to 17 of which 8 are called departments or institutes of geophysics and 9 are departments of meteorology. The total number of Bachelors' degrees given during the year from July 1, 1949, to June, 1950, was 301 of which 170 were in geophysics or geophysical engineering and 131 were in meteorology. The total number of Masters' degrees given in the same interval was 116—43 in geophysics and 73 in meteorology. Doctorates given were 22 in geophysics and 17 in meteorology.

A new movement is clearly evident. Geophysical exploration is being recognized more and more as the engineering occupation it really is and a professional consciousness is being felt. Perhaps it is not fantastic to look forward in a few years to an "American Society of Geophysical Engineers." The Committee is divided on the question whether it should be our Society. The following degrees: *Geophysical Engineer*, *Bachelor of Science in Geophysical Engineering*, and *Doctor of Geophysical Engineering* are being given at present.

In conclusion a word needs to be said about a proposal by Doctor H. W. Straley, III, to the Mineral Industry Education Division of the American Institute of Mining and Metallurgical Engineers to communicate with the Society of Exploration Geophysicsts, the American Geophysical Union, the American Meteorological Society, and the Seismological Society of America with a view toward the creation of a joint committee on geophysical education with rotating chairmanship. The experience of the SEG committee would lead it to believe that such a joint committee would be so unwieldy as to accomplish nothing unless it were set up as an entirely or almost entirely autonomous agency such as the Engineers Council for Professional Development with accrediting powers and were adequately financed for the purpose. It has been the consistent opinion of the members of the Standing Committee on Geophysical Education of the Society of Exploration Geophysicists that a *general* accrediting procedure would be a mistake. In so far as professional curricula in geophysical engineering are concerned, they fall within the jurisdiction of the ECPD and the proposed committee would be a duplication.

* Report of the Standing Committee on Geophysical Education, Society of Exploration Geophysicists. The members of this committee are: D. C. Skeels, M. King Hubbert, C. A. Heiland, Beno Gutenberg, Perry Byerly and Rev. J. B. Macelwane, chairman. Presented at the Annual Meeting of the Society at St. Louis, April, 1951.

TABLE I

School	Department Geophysics or Other	Students		Degrees in Geophysics July 1949 to June 1950			
		Undergraduate	Graduate	Bachelor	Master	Doctor	Other
Acadia U.	—	—	—	—	—	—	—
Alaska, U. of	Institute Physics	—	—	—	—	—	—
Alberta, U. of	Geology	—	—	—	—	—	—
American U.	—	—	—	—	—	—	—
Arizona, U. of	—	—	—	—	—	—	—
Arkansas, U. of	—	—	—	—	—	—	—
Beloit Col.	—	—	—	—	—	—	—
Birmingham Southern U.	—	—	—	—	—	—	—
Brigham Young U.	—	—	—	—	—	—	—
British Columbia U.	Physics	38	4	—	1	—	—
Brooklyn Polytech. Inst.	Civil Engr.	—	—	—	—	—	—
Brown U.	Oceanography*	—	—	—	—	—	—
Bucknell U.	—	—	—	—	—	—	—
California, Southern, U. of	Geology	—	—	—	—	—	—
California, U. Berkeley	Geol. Sciences	16	6	6	—	—	—
Calif. U., Los Angeles	Geoph. Inst.	—	—	—	—	—	—
	Met. Cur.	70	62	42	9	1	—
Calif. Inst. of Tech.	Geoph. Cur., Div. of Geo. Sciences	12	7	4	9	5	—
Chattanooga, U. of	Physics, Met.	—	—	—	—	—	—
Cincinnati, U. of	Geology, Met., Cur.	—	—	—	2†	—	—
Colgate U.	—	—	—	—	—	—	—
Colorado, U.	Geology, Physics	25	7	—	—	—	—
Colorado A. & M. Col.	Met., Civ. Engr.	—	—	—‡	—	—	—
Colorado Sch. of Mines	Geophysics	117	25	30‡	1	—	—
Columbia U.	Geology	—	10	—	—	2	—
Cornell U.	Conserv.	—	—	—	—	—	—
	Div. of Met.	—	1	—	—	—	—
Dalhousie U.	Physics	—	1	—	—	—	—
Dartmouth U.	—	—	—	—	—	—	—
Delaware, U. of	Met. Elective	—	9	—	—	—	—
Denver, U. of	—	—	—	—	—	—	—
DePauw U.	—	—	—	—	—	—	—
Drake U.	—	38	—	—	—	—	—
Florida State U.	Meteorology	7	8	—	—	—	—
Florida, U. of	Met. Maj.	2	—	—	—	—	—
Fordham U.	Physics	8	4	4§	2§	1§	—
Georgia Inst. of Tech.	Ceramics	1	—	—	—	—	—
Harvard U.	Geological Sciences	—	10	—	—	—	—
Heidelberg Col.	—	—	—	—	—	—	—
Houston, U. of	Geology	2 or 3	—	—	—	—	—
Idaho, U. of	Mining	—	—	—	—	—	—
Illinois, U. of	Mining & Geog.	—	—	—	—	—	—
Illinois, Southern U.	—	—	—	—	—	—	—
Iowa, State U. of	—	—	—	—	—	—	—
Iowa State Col.	Physics	—	—	—	—	—	—
John Carroll U.	Physics	—	—	—	—	—	—
Johns Hopkins U.	Geology, Oceanog., Geog.	—	—	—	—	—	—
Kansas, U. of	Geology	—	—	—	—	—	—

— Means none.
* Independent, but not full department.
† Geology Masters with Geophysical Theses.
‡ Geophysical Engineers.
§ With Geophysics concentration.

TABLE I—*Continued*

School	Department Geophysics or Other	Students		Degrees in Geophysics July 1949 to June 1950			
		Undergraduate	Graduate	Bachelor	Master	Doctor	Other
Kansas City, U. of	—	—	—	—	—	—	—
Kansas State Col.	Physics	—	—	—	—	—	—
Kent State U.	—	—	—	—	—	—	—
Laval U.	Engineering	—	—	—	—	—	—
Lehigh U.	Mining, Geology	8	1	—	—	—	—
Louisiana State U.	Geology	—	—	—	—	—	—
McMaster U.	—	—	—	—	—	—	—
Maine U.	—	—	—	—	—	—	—
Manhattan U.	Engineering	—	—	—	—	—	—
Marshall Col.	Geology	—	—	—	—	—	—
Massachusetts Inst. Tech.	Geology	12	7	3	—	—	—
	Meteorology	34	40	11	16	7	—
Miami U.	Met. Aeronaut.	—	—	—	—	—	—
Michigan, U. of	Geology	—	5	—	4	—	—
Michigan Col. M. & T.	Physics	2	1	—	1	—	—
Michigan State Col.	Physics	—	—	—	—	—	—
Middlebury Col.	—	—	—	—	—	—	—
McGill U.	Physics	13‖	1‖	—	3‖	2‖	—
Milwaukee-Downer Col.	Geography	—	—	—	—	—	—
Minnesota, U. of	Mines & Physics	1	2	—	—	—	—
Mississippi State Col.	Physics	—	—	—	—	—	—
Montana Sch. of Mines	Physics	—	—	—	—	—	—
Muskingum Col.	Met. Option	—	—	—	—	—	—
Nevada, U. of	Geol. & Eng., Met. Maj.	—	—	—	—	—	—
New Hampshire, U. of	—	—	—	—	—	—	—
New Mexico Inst. of M-T	Physics & Geophysics	14	5	6	1	—	—
New Mexico, Univ. of	Physics	—	—	—	—	—	—
	Met. Maj.	4	—	—	—	—	—
New York, City Col. of	Met. Maj. & Cur., Geol. & Phys.	28	—	8	—	—	—
New York U.	Eng. & Geol.	—	—	—	—	—	—
	Met. Maj. & Cur.	45	75	15	15	—	—
North Carolina, U. of	Geol. & Geog.	—	—	—	—	—	—
North Dakota, U. of	Geology	—	—	—	—	—	—
	Met., Geog.	3	—	—	—	—	—
Northwestern U.	Geology	—	—	—	—	—	—
Ohio U.	—	—	—	—	—	—	—
Ohio State U.	Met. Maj.	2	1	—	—	—	—
Ohio Wesleyan U.	—	—	—	—	—	—	—
Oklahoma A. & M. Col.	Phys., Met. Cur. & Minor, Geog.	5	—	7	—	—	—
Oklahoma, U. of	Phys., Geol. & Geog.	6	1	—	—	—	—
Omaha, U. of	—	—	—	—	—	—	—
Oregon, U. of	—	—	—	—	—	—	—
Oregon State Col.	Physics	—	—	—	—	—	—
	Geology	—	—	—	—	—	—
	Met. Option	8‖	3‖	—	—	—	—
Pennsylvania State Col.	Geoph. Mineral.	21	11	5	—	—	—
	Met. Cur.	47	9	15	2	1	—
Portland, U. of	—	—	—	—	—	—	—
Queen's U.	Geol. Sciences	—	—	—	—	—	—
Redlands, U. of	Geology	5	—	4¶	—	—	—
Rensselaer Poly. Inst.	Fuel Resources	2	—	—	—	—	—

‖ Physics.
¶ Geology.

TABLE I—*Continued*

School	Department Geophysics or Other	Students		Degrees in Geophysics July 1949 to June 1950			
		Undergraduate	Graduate	Bachelor	Master	Doctor	Other
Rutgers U.	—	—	—	—	—	—	—
St. Ambrose Col.	—	—	—	—	—	—	—
St. Louis U.	Geoph. & Geoph. Engr.	60	19	41	4	2	—
	Met. Cur.	13	11	4	1	—	—
St. Mary's Col.—Winona	—	—	—	—	—	—	—
St. Thomas, Col. of	—	—	—	—	—	—	—
San Diego State Col.	—	—	—	—	—	—	—
San Francisco State Col.	—	—	—	—	—	—	—
San Jose State Col.	Div. Nat. Science	3	1	—	—	—	—
Saskatchewan, U. of	Phys. & Geol. Honors	—	—	—	—	—	—
South Carolina, U. of	—	—	—	—	—	—	—
South Dakota, U. of	—	—	—	—	—	—	—
South Dak. Sch. of Mines	Geol. Engr.	—	—	—	—	—	—
Stanford U.	Sch. of Min. Science	3	1	—	—	—	—
Tennessee, E. State Col.	—	—	—	—	—	—	—
Tennessee, U. of	Met., Geol. & Geog.	—	—	—	—	—	—
Texas Col. of Arts & Ind.	Geophysics	—	—	—	—	—	—
Texas, A. & M. Col.	Geol., Phys., Oceanog. & Geog.	8	—	2	—	—	—
Texas Christian U.	Physics, Met. Courses	40**	—	—	—	—	—
Texas Tech. Col.	Petr. Geol.	6	—	—	—	—	—
	Met. Option	6	—	—	—	—	—
Texas, U. of	Phys., Geol.	45	—	—	—	—	—
	Met. Cur.	16	—	—	—	—	—
Toronto, U. of	Geoph., Sect. Phys.	6††	53	10	35	—	—
Tuft's Col.	Geol., Met., Phys.	—	—	—	—	—	—
Tulane U.	Geology	—	—	—	—	—	—
Tulsa, U. of	Physics	30–40	—	8	—	—	—
Utah, U. of	Geophysics	15	2	3	—	—	—
	Meteorology	25	6	7	1	—	—
Valparaiso U.	—	—	—	—	—	—	—
Washburn Mun. U.	—	—	—	—	—	—	—
Washington, State Col. of	Civil Engr.	—	—	—	—	—	—
Washington U.	Geol. Engr.	25	9	2	5	1	—
	Met., Geog.	3–4	—	—	—	—	—
Washington Col.	Geol., Phys.	—	—	—	—	—	—
Washington, George, U.	—	—	—	—	—	—	—
Washington-Lee U.	—	—	—	—	—	—	—
Washington, U. of	Geology	—	—	—	—	—	—
	Meteorology	50	7	22	1	—	—
Wayne U.	Geology	—	—	—	—	—	—
Western Ontario, U. of	Physics	—	—	—	—	—	—
West Virginia, U. of	Mines	24	6	—	—	—	—
	Met.Cur.	—	—	—	—	—	—
West Virginia State Col.	—	—	—	—	—	—	—
Western Reserve U.	—	—	—	—	—	—	—
Wichita, U. of	—	—	—	—	—	—	—
Williams Col.	Geology	—	—	—	—	—	—
	Astronomy	—	—	—	—	—	—
Wisconsin, U. of	Geology	2	8	—	—	1	—
	Met. Cur.	10	5	1	1	—	—
Wittenberg Col.	—	—	—	—	—	—	—
Wyoming, U. of	—	—	—	—	—	—	—
Xavier U.	Physics	—	—	—	—	—	—
Yale U.	Met., Geol.	—	—	—	—	—	—

** Taking courses.
†† There will also be 30 undergraduates taking 1 or more courses in Geophysics.

TABLE II

E = Elementary course; A = Advanced Undergraduate course; G = Graduate course

	Applied Geophysics or Geophysical Engineering					Geophysical Sciences									
	General	Theory	Methods of Exploration	Instruments	Other	General	Geodesy (Gravity)	Geoelectricity	Geomagnetism	Hydrology	Oceanography	Meteorology	Seismology	Volcanology	Other
Acadia U.	—	—	—	—	—	—	—	—	—	—	—	2E	—	—	—
Alaska, U. of	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
Alberta, U. of	—	—	1E	—	—	—	—	—	—	—	—	2E	—	—	—
Arizona, U. of	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
Arkansas, U. of	—	—	—	—	—	—	—	—	—	—	—	4E	—	—	—
Beloit Col.	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
Brigham Young U.	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	2A	—	—	—
British Columbia, U.	—	1A	1A	1A	—	—	—	—	—	—	5G	2E	—	—	—
	—	1G	—	—	—	—	—	—	—	—	—	—	—	—	—
Brooklyn Polytech. In.	—	—	—	—	—	—	—	—	—	1G	—	—	—	—	—
Brown U.	—	—	—	—	—	—	—	—	—	—	1E	1A	—	—	—
	—	—	—	—	—	—	—	—	—	—	2A	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	2G	—	—	—	—
Bucknell U.	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
Calif., Southern, U.	—	—	—	—	—	—	—	—	—	—	1G	—	—	1G	—
Calif., U. Berkeley	2E	—	—	—	—	1E	—	—	—	—	—	1E	1E	1G	—
	3A	—	—	—	—	2A	—	—	—	—	—	—	1A	—	—
	—	—	—	—	—	1G	—	—	—	—	—	—	4G	—	—
Calif. U. Los Angeles	—	2E	—	—	—	—	2E	2E	2E	—	10A	2E	1E	—	—
	—	3A	—	—	—	—	2A	2A	2A	—	10G	16A	1A	—	—
	—	2G	—	—	—	—	2G	2G	2G	—	—	9G	2G	—	—
Calif. Inst. of Tech.	—	1A	1A	1G	—	1A	—	—	—	—	—	—	—	—	—
	—	—	4G	—	—	2G	—	—	—	—	—	—	1A	—	—
	—	—	—	—	—	—	—	—	—	—	—	—	4G	—	—
Chattanooga, U.	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
Cincinnati, U. of	1E	—	—	—	—	—	—	—	—	—	—	2E	—	—	—
	1A	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Colgate U.	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
Colorado, U. of	—	1E	1E	—	—	—	—	—	—	—	—	—	—	—	—
Colorado A. & M. Col.	—	—	—	—	—	—	—	—	—	—	—	2E	—	—	—
Colorado Sch. of Mines	—	5A	2E	2A	2A	—	—	—	—	—	—	—	—	—	—
	—	3G	5A	2G	2G	—	—	—	—	—	—	—	—	—	—
	—	—	4G	—	—	—	—	—	—	—	—	—	—	—	—
Columbia U.	1G	—	—	—	—	—	—	—	—	—	—	1E	1G	1A	—
	—	—	—	—	—	—	—	—	—	—	—	1A	—	1G	—
Cornell U.	—	—	—	—	—	—	—	—	—	—	1E	4E	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	1A	—	—	—
Dalhousie U.	1G	1G	1G	—	—	—	—	—	—	—	—	—	—	—	—
Dartmouth Col.	—	—	—	—	—	—	—	—	—	—	—	3E	—	—	—
Delaware, U. of	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
Denver, U. of	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
DePauw U.	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
Drake U.	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
Florida State U:	—	—	—	—	—	—	—	—	—	—	—	6E	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	6A	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	3G	—	—	—
Florida, U.	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	1A	—	—	—
Fordham U.	—	—	—	1A	—	—	—	1A	—	—	—	2A	1A	—	—
	—	—	—	1G	—	—	—	1G	—	—	—	—	1G	—	—

TABLE II—*Continued*

	Applied Geophysics or Geophysical Engineering					Geophysical Sciences									
	General	Theory	Methods of Exploration	Instruments	Other	General	Geodesy (Gravity)	Geoelectricity	Geomagnetism	Hydrology	Oceanography	Meteorology	Seismology	Volcanology	Other
Georgia Inst. of Tech.	1A	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Harvard U.	—	—	—	—	—	1E	—	—	—	1A	1A	—	1E	1A	—
	—	—	—	—	—	1A	—	—	—	—	—	—	1A	—	—
Heidelberg Col.	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
Houston, U.	1E	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
	1A	—	—	—	—	—	—	—	—	—	—	1A	—	—	—
Idaho, U. of	1E	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Illinois, U.	1E	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
Illinois, Southern U.	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
Iowa, State U. of	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
Iowa State Col.	1E	—	—	—	—	—	—	—	—	—	—	—	—	—	—
John Carroll U.	—	—	—	—	1G	—	—	—	—	—	—	1E	—	—	—
Johns Hopkins U.	1A	—	—	—	—	—	—	—	—	—	1E	1E	—	—	—
	—	—	—	—	—	—	—	—	—	—	1A	1A	—	—	—
	—	—	—	—	—	—	—	—	—	—	8G	—	—	—	—
Kansas, U. of	—	—	1E	—	—	—	—	—	—	—	—	—	1E	—	—
Kansas City, U. of	—	—	—	—	—	—	—	—	—	—	—	3E	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	3A	—	—	—
Kansas State Col.	—	1E	1E	—	—	—	—	—	—	—	—	2E	—	—	—
Kent State U.	—	—	—	—	—	—	—	—	—	—	—	3E	—	—	—
Laval U.	1E	—	—	—	—	—	—	—	—	—	—	2E	—	—	—
Lehigh U.	2E	—	—	—	—	—	—	—	—	—	—	2E	—	—	—
	2A	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Louisiana State U.	1E	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	1A	—	—	—	—	—	—	—	—	—	—	—	—	—	—
McMaster U.	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
Maine, U. of	—	—	½E	—	—	—	—	—	—	—	—	—	—	—	—
Manhattan U.	—	—	—	—	—	—	—	—	—	1E	—	—	—	—	—
Marshall Col.	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
Mass. Inst. Tech.	1G	1E	—	—	—	—	—	—	—	—	—	12E	—	—	—
	—	1G	—	—	—	—	—	—	—	—	—	9A	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	15G	—	—	—
Miami U.	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	1A	—	—	—
Michigan, U. of	1A	1G	1G	—	—	1A	—	—	—	—	—	1E	—	—	—
Michigan Col. M. & T.	—	1A	2A	—	1A	—	—	—	—	—	—	1E	—	—	—
	—	1G	—	—	—	—	—	—	—	—	—	—	—	—	—
Michigan State Col.	1E	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
Middlebury Col.	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
McGill U.	1E	—	—	—	—	—	—	—	—	—	—	1A	—	—	—
Milwaukee-Downer Col.	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
Minnesota, U. of	—	—	1E	—	—	1E	—	—	—	—	—	1A	1E	—	—
Mississippi State Col.	1E	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Montana Sch. of Mines	1E	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Muskingum Col.	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
Nevada, U. of	—	—	1E	—	—	—	—	—	—	1E	—	1E	—	—	—
New Hampshire, U. of	—	—	—	—	—	—	—	—	—	—	—	2E	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	1A	—	—	—
New Mex. In. M. & T.	2E	—	—	—	1G	—	—	—	—	—	—	—	—	—	—
New Mexico, U. of	2G	—	—	—	—	1A	—	—	—	—	—	2E	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	1A	—	—	—

TABLE II—*Continued*

	Applied Geophysics or Geophysical Engineering					Geophysical Sciences									
	General	Theory	Methods of Exploration	Instruments	Other	General	Geodesy (Gravity)	Geoelectricity	Geomagnetism	Hydrology	Oceanography	Meteorology	Seismology	Volcanology	Other
New York, City Col. of	—	—	—	—	—	—	—	—	—	—	—	6E	—	—	—
New York U.	2G	—	—	—	—	—	—	—	—	1E	4G	3E	—	—	—
	—	—	—	—	—	—	—	—	—	1G	—	8A	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	17G	—	—	—
North Carolina, U. of	1E	—	—	—	—	—	—	—	—	—	—	—	—	1E	—
	1A	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	1G	—	—	—	—	—	—	—	—	—	—	—	—	—	—
North Dakota, U. of	—	—	⅓E	—	—	—	—	—	—	—	—	2E	—	—	—
Northwestern U.	1G	—	—	—	—	—	—	—	—	—	—	2E	—	—	—
Ohio U.	—	—	—	—	—	—	—	—	—	—	—	2E	—	—	—
Ohio State U.	—	—	—	—	—	—	—	—	—	—	—	2⅔E	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	⅔A	—	—	—
Ohio Wesleyan U.	—	—	—	—	—	—	—	—	—	—	—	2E	—	—	—
Oklahoma A. & M. Col.	1E	—	—	—	—	—	—	—	—	—	—	6E	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	3A	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	1G	—	—	—
Oklahoma, U. of	—	1A	2E	—	—	—	—	—	—	—	—	2E	—	—	—
Omaha, U. of	—	—	—	—	—	—	—	—	—	—	—	2E	—	—	—
Oregon, U. of	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
Oregon State Col.	⅔E	—	—	—	—	—	—	—	—	⅔A	—	⅔E	1⅓G	—	—
	—	—	—	—	—	—	—	—	—	—	—	⅔A	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	1⅓G	—	—	—
Pennsylvania St. Col.	—	1G	2E	—	2E	1E	—	—	—	—	—	7E	—	—	—
	—	—	2A	—	1G	—	—	—	—	—	—	15A	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	19G	—	—	—
Portland, U. of	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
Queen's U.	1E	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Redland, U. of	—	—	—	—	—	1E	—	—	—	—	—	—	—	—	—
Rensselaer Poly. Inst.	1E	—	—	—	—	1E	—	—	—	—	—	—	1A	—	—
Rutgers U.	—	—	—	—	—	—	—	—	—	—	—	2E	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	2A	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	2G	—	—	—
St. Ambrose Col.	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
St. Louis U.	—	5A	2A	—	—	—	—	1G	1G	2A	—	3E	7A	—	—
	—	—	—	—	—	—	—	—	—	1G	—	13A	3G	—	—
	—	—	—	—	—	—	—	—	—	—	—	2G	—	—	—
St. Mary's Col. (Winona)	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
St. Thomas, Col. of	—	—	—	—	—	—	—	—	—	—	—	2E	—	—	—
San Diego State Col.	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
San Francisco St. Col.	—	—	—	—	—	—	—	—	—	—	—	1A	—	—	—
San Jose State Col.	⅔E	—	—	—	—	—	—	—	—	—	—	4E	—	⅔E	—
Saskatchewan, U.	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
South Carolina, U.	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
South Dakota, U.	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
South Dak. Sch. of M.	1E	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Stanford U.	—	1A	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	1G	—	—	—	—	—	—	—	—	—	—	—	—	—
Tennessee, E. St. Col.	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
Tennessee, U. of	—	—	—	—	—	—	—	—	—	—	—	3E	—	—	—
Texas Col. of A. & I.	—	1A	—	—	—	—	—	—	—	—	—	—	—	—	—

TABLE II—*Continued*

	Applied Geophysics or Geophysical Engineering					Geophysical Sciences									
	General	Theory	Methods of Exploration	Instruments	Other	General	Geodesy (Gravity)	Geolectricity	Geomagnetism	Hydrology	Oceanography	Meteorology	Seismology	Volcanology	Other
Texas, A. & M. Col.	—	1A	—	—	2A	—	—	—	—	—	17G	1E	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	1G	—	—	—
Texas Christian U.	1E	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	1A	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	1G	—	—	—
Texas Tech. Col.	—	2E	—	—	—	—	—	—	—	1E	2E	2A	2E	1E	—
	—	—	—	—	—	—	—	—	—	1G	2G	—	2G	1G	—
Texas, U. of	—	—	1A	—	—	—	—	—	—	—	1A	1E	—	—	1G
	—	—	—	—	—	—	—	—	—	—	—	9A	—	—	—
Toronto, U. of	—	2A	3A	3A	4A	—	2G	—	—	—	—	2A	2G	—	—
	—	—	—	—	2G	—	—	—	—	—	—	27G	—	—	—
Tufts, Col.	—	—	—	—	—	—	—	—	—	—	—	2E	—	—	—
Tulane U.	—	2E	2E	—	—	—	—	—	—	—	—	—	—	—	—
Tulsa, U. of	—	—	5A	—	3E	—	—	—	—	—	—	—	—	—	—
Utah, U. of	—	—	$1\frac{1}{3}$E	$2\frac{2}{3}$A	—	—	—	—	—	2E	$\frac{2}{3}$G	3G	$\frac{2}{3}$G	—	—
	—	—	$2\frac{2}{3}$A	—	—	—	—	—	—	2A	—	$1\frac{1}{3}$E	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	$11\frac{2}{3}$A	—	—	—
Valparaiso U.	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
Washburn Muni. U.	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
Washington, St. Col. of	—	—	—	—	—	—	—	—	—	1E	—	1E	—	—	—
Washington U.	—	1A	1A	—	2G	—	—	—	—	—	—	1E	—	1E	—
	—	—	2G	—	—	—	—	—	—	—	—	—	—	2A	—
	—	—	—	—	—	—	—	—	—	—	—	—	—	4G	—
Washington Col.	—	—	—	—	—	—	—	—	—	1A	1E	—	—	—	—
Washington, Geo., U.	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
Washington & Lee U.	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
Washington, U. of	—	—	—	—	—	—	—	—	—	—	—	1E	1E	—	—
	—	—	—	—	—	—	—	—	—	—	—	12A	1A	—	—
	—	—	—	—	—	—	—	—	—	—	—	8G	—	—	—
Wayne U.	1A	—	—	—	—	—	—	—	—	—	—	2E	—	—	—
Western Ontario, U. of	—	—	—	—	—	1A	—	—	—	—	—	—	—	—	—
West Virginia U.	1E	—	—	1E	—	—	—	—	—	—	—	2E	1E	—	—
West Virginia St. Col.	—	—	—	—	—	—	—	—	—	—	—	2E	—	—	—
Western Reserve U.	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
Wichita, U. of	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
Williams Col.	1E	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
Wisconsin, U. of	1E	—	—	—	—	—	—	—	—	—	1E	1E	—	—	—
	1G	—	—	—	—	—	—	—	—	—	—	5A	—	—	—
Wittenberg Col.	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—
Wyoming, U. of	—	—	—	—	—	—	—	—	—	—	—	$\frac{2}{3}$E	—	—	—
Xavier U.	—	—	—	—	—	1A	—	—	—	—	—	—	1A	—	—
Yale U.	—	—	—	—	—	—	—	—	—	—	—	1E	—	—	—

PATENTS

O. F. RITZMANN*

ELECTRICAL PROSPECTING

U. S. No. 2,542,462. C. I. Beard. Iss. 2/20/51. App. 8/27/49. Assign. Socony-Vacuum Oil Co., Inc.

Surface Wave Cancellation Electrical Prospecting. A method of electromagnetic prospecting in which an impulse is generated in a homogeneous model earth made of non-ferrous metal simultaneously with the pulse in the real earth and the surface wave picked up from the model and subtracted from the pulse picked up from the real earth.

U. S. No. 2,546,771. R. P. Mork. Iss. 3/27/51. App. 10/20/49. Assign. General Electric Co.

Metal Detector. A coil system for detecting metal on a conveyor belt having above and below the belt primary coils with their axes parallel to the moving belt and connected so that their fields are aiding, and also above and below the belt secondary coils perpendicular to the primary coils and connected with their outputs in opposition.

GEOCHEMICAL PROSPECTING

U. S. No. 2,545,900. R. M. Squires. Iss. 3/20/51. App. 1/24/47. Assign. Socony-Vacuum Oil Co., Inc.

Apparatus for Collecting Soil Gas Samples. A device by which soil gas is drawn from a shallow hole through a sample tube into a closed container by withdrawing water from the container at constant suction.

MAGNETIC PROSPECTING

U. S. No. 2,539,270. M. Puranen and A. A. Kahma. Iss. 1/23/51. App. 8/22/42 and 6/4/47.

Method of Magnetographic Surveying. A method of aeromagnetic surveying in which a group of magnetograph-carrying airplanes fly over the area in formation and another plane at a higher altitude periodically photographs the ground and the superimposed recording planes in order to fix their locations.

U. S. No. 2,541,213. C. S. Davidson. Iss. 2/13/51. App. 10/10/47.

Magnetometer. A vertical magnetometer having a pivoted needle with counterweight to which small masses are attached by rods of different coefficients of expansion so that temperature changes will shift the center of gravity to compensate for changes in magnetic moment of the needle.

U. S. No. 2,543,843. A. Frosch. Iss. 3/6/51. App. 7/8/48. Assign. Standard Oil Development Co.

Magnetic Field Measuring Device. A magnetic detector having a transformer with a thin core placed in the field, the primary of the transformer being excited at one frequency and the secondary at a lower frequency and variations in the high-frequency secondary voltage measured.

SEISMIC PROSPECTING

U. S. No. 2,539,220. L. F. Athy and H. R. Prescott. Iss. 1/23/51. App. 6/22/44. Assign. Continental Oil Co.

Seismographic Record Correlation System. A seismograph recording system for continuous profiling in which two recordings are made with the arrangement of traces reversed and the records separated and assembled with those of adjacent spreads with time corrected for shot-point weathering and elevation.

* Gulf Oil Corporation, Patent Department.

U. S. No. 2,542,227. R. K. Bernhard. Iss. 2/20/51. App. 7/2/46.

Testing Apparatus. A mechanical oscillator for producing continuous vibrations and having three parallel shafts one of which rotates opposite from the other two and all three shafts carrying eccentric weights with independent adjustments for their eccentricities and phase angles.

U. S. No. 2,544,819. J. J. Babb and N. J. Smith. Iss. 3/13/51. App. 8/29/47. Assign. Babb to Geophysical Service Inc. and Smith to The California Co.

Apparatus for Marine Seismic Prospecting. A submarine seismometer spread having a heavy cable with branch cables at each seismometer location, the seismometer being mounted on a pivot at the end of its branch cable and with sufficient buoyancy to keep the branch cable vertical.

U. S. No. 2,545,380. T. C. Poulter. Iss. 3/13/51. App. 6/3/50. Assign. Institute of Inventive Research.

Seismic Exploration Employing Elevated Charges. A method of seismic exploration in which a number of charges are exploded at a uniform distance above the earth's surface, this distance being such that the shock wave strikes the earth with supersonic velocity.

WELL LOGGING

U. S. No. 2,539,758. D. Silverman and R. W. Stuart. Iss. 1/30/51. App. 12/26/45 Assign. Stanolind Oil and Gas Co.

Means for Logging Drilling Rates. A drilling-rate recorder in which the indication is corrected for changes in mud pressure and changes in weight on drill stem.

U. S. No. 2,541,341. K. C. Crumrine. Iss. 2/13/51. App. 7/7/47. Assign. The Texas Co.

Well Logging. A neutron well-logging system in which the formations are bombarded with fast neutrons and scattered slow neutrons are detected by a proportional counter with an amplitude discriminator to eliminate gamma-ray background.

U. S. No. 2,543,532. J. Neufeld. Iss. 2/27/51. App. 8/6/48. Assign. Well Surveys, Inc.

Multiplex Well Logging System. A system for logging several parameters over a single cable by electronically switching to the various elements in the well apparatus, recording the composite signal at the surface on a magnetic tape and obtaining separate records by a subsequent analysis with synchronous switching to separate recorders.

U. S. No. 2,543,675. L. M. Swift. Iss. 2/27/51. App. 7/15/48. Assign. Well Surveys, Inc.

Method and Apparatus for Adjusting Spacing Between Neutron Source and Detector. A thick-walled tubular shield for a neutron source with top and bottom closures and cylindrical slugs which may be inserted above or below the source to vary its distance from the end attached to the detector.

U. S. No. 2,543,676. J. M. Thayer and R. E. Fearon. Iss. 2/27/51. App. 7/28/49. Assign. Well Surveys Inc.

Method and Apparatus for Neutron Well Logging. A neutron well-logging system in which the formations are bombarded with fast neutrons and returning neutrons detected, and in which the effect of a particular element is emphasized by first logging without a shield on the detector and then logging with a shield of the particular element and subtracting the two logs.

U. S. No. 2,544,100. J. E. Miller. Iss. 3/6/51. App. 9/24/48.

Apparatus for Measuring Distances Within Bores. A radar-type fluid-level indicator in which the transmitter is connected to the annular space of the well by a wave guide and a branch guide connects to the receiver for detecting reflected waves.

U. S. No. 2,544,569. D. Silverman. Iss. 3/6/51. App. 12/17/46. Assign. Stanolind Oil and Gas Co.

Signaling System. A system for logging while drilling in which electric signals are impressed on the earth by the well apparatus and picked up with electrodes at the surface, and also having a seismic detector on the surface of the ground whose output is combined in opposition with the electric signal so as to cancel out noise produced by the seismic-electric effect.

MISCELLANEOUS

U. S. No. 2,539,355. P. P. Reichertz. Iss. 1/23/51. App. 8/6/47. Assign. Socony-Vacuum Oil Co., Inc.

Apparatus for Measuring Interstitial Water Content, Permeability, and Electrical Conductivity of Well Cores. An apparatus for testing a plastic-coated cylindrical core sample and having electrodes in fluid inlet and outlet clamps which are placed against the ends of the core.

U. S. No. 2,545,179. V. Voorhees. Iss. 3/13/51. App. 4/7/48. Assign. Standard Oil Co.

Submarine Marker with Sonic Signal Generators. A submarine surveying marker having a power unit with radio transmitter for rough location finding and three submerged short-wave sonic generators for accurately marking the location.

U. S. No. 2,546,523. F. F. Reynolds. Iss. 3/27/51. App. 8/20/47.

Marsh Vehicle. A marsh buggy whose load-carrying platform is mounted between two pontoons with sprockets which drive endless-chain belts connected by transverse slats.

SELECTED LIST OF U. S. PATENTS ISSUED DURING THE FIRST QUARTER OF 1951

Patent No.	*Subject*	*Patent No.*	*Subject*	*Patent No.*	*Subject*
2,536,025	12	2,536,683	312	2,537,729	288
2,536,029	224	2,536,728	312	2,537,731	228
2,536,030	224	2,536,770	316	2,537,753	428
2,536,031	288	2,536,771	436	2,537,775	288
2,536,037	16	2,536,802	4	2,537,844	16
2,536,101	428	2,536,810	224	2,537,858	428, 324
2,536,111	188	2,536,870	492	2,537,911	12
2,536,117	428	2,536,991	308	2,537,932	16
2,536,126	224	2,537,025	236	Re. 23,327	484
2,536,128	12	2,537,039	136	2,537,952	316
2,536,131	308	2,537,105	324	2,537,973	316
2,536,132	224	2,537,137	324	2,538,026	484
2,536,179	484	2,537,139	316	2,538,029	460
2,536,193	468	2,537,162	80	2,538,114	140, 12
2,536,260	224	2,537,240	16	2,538,158	428
2,536,272	224	2,537,253	484	2,538,164	484
2,536,303	80, 404	2,537,260	224	2,538,226	68
2,536,314	308	2,537,498	200	2,538,253	68
2,536,346	316	2,537,569	468	2,538,303	16
2,536,433	312	2,537,574	316	2,538,405	484
2,536,465	200	2,537,596	16	2,538,444	12
2,536,488	316	2,537,597	16	2,538,621	484
2,536,493	460	2,537,628	68	2,538,622	440
2,536,496	312	2,537,657	224	2,538,632	308
2,536,509	312	2,537,668	284	2,538,636	68
2,536,664	12	2,537,723	484	2,538,710	168

Patent No.	Subject
2,538,740	160
2,538,800	316
2,538,824	288
2,538,843	16
2,538,892	224
2,538,893	224
2,538,981	224
2,539,001	108
2,539,009	324
2,539,047	92
2,539,102	308
2,539,121	224
2,539,158	160
2,539,163	16
2,539,196	308
2,539,203	308
2,539,220[a]	352
2,539,270[a]	232
2,539,355[a]	88
2,539,400	224
2,539,402	316
2,539,405	312
2,539,411	216
2,539,413	316
2,539,418	288
2,539,482	312
2,539,488	484
2,539,535	484
2,539,553	468, 316
2,539,593	484
2,539,616	68
2,539,665	200
2,539,671	484
2,539,672	484
2,539,758[a]	100
2,539,772	180
2,539,832	324
2,539,833	288
2,539,837	224
2,539,876	224
2,539,892	288
2,539,901	316
2,539,905	312
2,540,035	108
2,540,049	140, 308
2,540,096	404
2,540,105	492
2,540,150	16
2,540,176	288
2,540,184	48
2,540,187	484
2,540,194	484
2,540,261	308
2,540,299	224
2,540,310	308
2,540,385	80
2,540,412	484
2,540,413	312
2,540,414	312
2,540,487	484
2,540,506	316
2,540,536	316
2,540,588	228
2,540,589	228
2,540,699	200
2,540,711	224
2,540,780	420
2,540,796	484
2,540,822	16
2,540,851	484
2,540,870	140
2,540,963	460
2,541,030	316
2,541,040	312
2,541,066	316
2,541,102	412
2,541,125	312
2,541,136	224
2,541,213[a]	232
2,541,277	68, 16
2,541,334	136
2,541,341[a]	304
2,541,389	136
2,541,576	200
2,541,578	148
2,541,618	232
2,541,656	236
2,541,785	80
2,541,824	68
2,541,877	416
2,541,878	16, 68
2,541,982	316
2,542,017	484
2,542,018	216
2,542,032	316
2,542,045	484
2,542,075	484
2,542,076	288
2,542,160	68
2,542,168	200
2,542,202	16
2,542,227[a]	76
2,542,304	308
2,542,355	288
2,542,414	288
2,542,440	308
2,542,457	484
2,542,462[a]	132
2,542,478	68
2,542,490	68
2,542,506	224
2,542,590	224
2,542,594	12
2,542,822	140
2,542,893	140
2,542,905	288
2,542,983	316
2,543,002	312
2,543,020	148
2,543,021	316
2,543,034	216
2,543,057	136
2,543,081	312
2,543,127	484
2,543,442	68
2,543,448	316
2,543,449	316
2,543,454	312
2,543,483	224
2,543,532[a]	516
2,543,570	140
2,543,573	492
2,543,588	148
2,543,650	68
2,543,655	484
2,543,675[a]	304
2,543,676[a]	304
2,543,753	16
2,543,769	316
2,543,782	316
2,543,814	48
2,543,823	48
2,543,843[a]	232
2,543,859	236, 168
2,543,861	80
2,544,078	168, 416
2,544,100[a]	520
2,544,261	196
2,544,262	200
2,544,293	316

Patent No.	Subject	Patent No.	Subject	Patent No.	Subject
2,544,355	316	2,545,007	484	2,546,370	316
2,544,400	428	2,545,024	48	2,546,403	288
2,544,412	276	2,545,101	484	2,546,523*	490
2,544,438	180	2,545,123	68	2,546,571	288
2,544,529	188	2,545,179*	436, 444	2,546,632	392
2,544,536	484	2,545,270	136	2,546,668	392
2,544,567	288	2,545,380*	360	2,546,669	392
2,544,569*	516	2,545,503	316	2,546,670	392
2,544,587	68, 444	2,545,655	68	2,546,686	32
2,544,612	288	2,545,737	484	2,546,715	168
2,544,624	324	2,545,754	312	2,546,771*	132
2,544,653	316	2,545,830	216	2,546,796	428
2,544,669	316	2,545,859	484	2,546,806	76
2,544,677	312	2,545,900*	400	2,546,821	224
2,544,686	444, 16	2,545,935	68, 16	2,546,829	224
2,544,717	236	2,545,961	484	2,546,832	200
2,544,718	236	2,545,975	524	2,546,836	16
2,544,738	428	2,546,048	308	2,546,850	224
2,544,767	16	2,546,155	484	2,546,927	224
2,544,819*	360	2,546,156	68	S.N. 704,389	484
2,544,863	68	2,546,158	16	S.N. 24,636	196
2,544,908	520	2,546,170	316		
2,544,928	308	2,546,256	140		

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Crystal Growth, by H. E. Buckley, John Wiley and Sons, Inc., New York, 1951, 571 pp., $9.00.

In this book, Dr. Buckley, Senior Lecturer in the crystallography department at the University of Manchester, has provided a comprehensive digest of the literature on crystal growth, with many illustrations from his own research on the subject. He describes briefly apparatus for growing crystals from solution, from melts, from vapor, or by means of electrolysis. These descriptions are sufficient to introduce one to commercial growth of Rochelle salt, ADP, quartz, or other piezoelectric crystals, and the necessary references are given for a more detailed study. Metal crystals and artificial gems are also considered. He discusses growth from solution in considerable detail and reviews several theories of crystal growth in the order of their historical importance.

Many photographs show the vast changes in form of a crystal caused by the presence of minute quantities of impurities added to the solution from which it is formed. The opinion of the reviewer based on the body of the book that some of these peculiar growth phenomena are pretty well understood was sadly shaken by an appendix which lists dozens of experiments in which crystals were changed from fine needles to plates or from cubes to octohedra by adding traces of Pontacyl Fast Pink BL Conc., chromotrope 2R (no. 45), or some other exotic compound.

There is a part of a chapter devoted to crystallization of minerals. The recommendation is made that laboratory experiments be exploited further as a means of studying the more complex crystallization from a melt represented on a grand scale by a magmatic mass in the earth. Formation of snow crystals is also touched on briefly.

This book is recommended as an introduction to a complex topic and as a bibliography for more detailed study of the field.

J. EDWARD WHITE
Magnolia Petroleum Company

How Oil is Found, by W. A. Ver Wiebe, Wichita, Kansas, 1951, 247 pp.

This 247 page lithoprinted book is sufficiently elementary that it should hold the interest of anyone without prior training in geology or geophysics who may wish to acquaint himself with the fundamental principles involved in the location of petroleum or natural gas. In keeping with this objective, the author scrupulously defines all technical terms as he introduces them in the course of his presentation.

The scope and organization of the book can be best demonstrated by quoting the titles of its eight chapters: "Seepages Point the Way," "The Oil Rocks," "Time and Place of Rock Formation," "That Magic Word Structure," "How Oil is Formed," "How Far Does Oil Travel?," "Where Does Oil Accumulate?," and "Methods Used in Oil Finding."

In the first chapter, numerous examples are given of how early fields were discovered by petroleum seepages. The second chapter gives an elementary discussion of sedimentary petrology, the third of physical and historical geology, and the fourth of structural geology. In the chapter on structure, the meaning of contour maps is explained for those who have had no previous contact with them.

The chapters on origin, migration and accumulation occupy about half of the book. While a number of hypotheses on these proceses are discussed, the bulk of the material consists of subsurface maps and cross sections of oil fields and petroliferous areas. Although these are highly informative, they cast little light on the mechanisms involved.

The last chapter is probably of greatest interest to geophysicists but will not be likely to contain any material not known to them already. Here the reader is introduced to nearly all the important methods of drilling, logging and prospecting. Examples are given to demonstrate the type of information secured by the various techniques. This is quite an adequate nontechnical treatment.

The book contains 300 illustrations which are reproduced unusually clearly and attractively in view of the inherent limitations of the litho-printing process. Many are full page size. The majority of the illustrations are geologic cross-sections or contour maps, which constitute particularly useful visual aids to a comprehension of the subject matter.

The book is particularly recommended to a student entering the field of geophysical prospecting after specialized training in physics or engineering. It should go far toward giving him a well-rounded background for his new type of activity.

R. A. SIMON
Magnolia Petroleum Company

Petroleum Geology, by Kenneth K. Landes, John Wiley and Sons, New York, 1951, 660 pp., $10.00.

For many years the output of published material relating to petroleum geology has been so voluminous that few persons working in it or in related fields have been able to keep informed on more than small sectors of this highly important subject. For a long time there has been a definite need for someone who has kept up with all developments in the field to organize this knowledge and, by extracting the essence, to present it in a synthesis of readable form and manageable length for the benefit of others who have neither the time nor the skill to do it for themselves. In *Petroleum Geology*, Professor Landes, who is Chairman of the Geology Department at the University of Michigan, has filled this need in admirable fashion.

The book has three major divisions, entitled "Techniques of the Petroleum Geologist," "Geological Occurrence of Petroleum," and "Present and Future Oil Supplies."

The first of these sections is given least emphasis because, as the author points out in the preface,

the technical aspects of oil finding are best learned on the job. Here surface geology, geophysical techniques, and logging are touched on but briefly. Thus the reader whose primary interest is in the *methods* of exploration and exploitation will look elsewhere for detailed information.

The section on geologic occurrence is outstanding for several reasons. In about 200 pages the author discusses in masterly style the processes by which oil is formed, transported and trapped. Where the mechanisms are controversial, as most of them are, he presents the various theories and concepts, along with the evidence for each, and evaluates each on the basis of his own observations. The long discussion on oil traps classifies the various types of trapping and illustrates each by examples of how oil has accumulated in various fields. The form in which the author presents these examples is worthy of special mention. For each field there is a page of diagrams including an inset map of the state or country on which the field is located by a conspicuous arrow, one or more contour maps of key horizons and usually a cross-section showing the field's subsurface structure. On the opposite page (or in many cases at the bottom of a long sheet folded into the book) is a terse discussion of the field which in every case considers the question of how the oil migrated to its present place of accumulation.

The last section, mainly on distribution of oil and gas fields, is encyclopedic in scope and gives a complete and well balanced although concise account of all the world's oil-producing areas. There is a profusion of maps showing the geologic features of each province as well as the distribution of oil. Contour maps and cross-sections of representative fields are liberally provided to illustrate the type of accumulation in each area.

The discussion of geophysical prospecting takes up only nine pages in the section on Techniques, so that there is space only for a brief summary of principles and operational methods. Two minor errors were noted in this portion. In the paragraphs on the magnetic method it is stated that the magnetic readings are corrected for latitude, placed on the map and contoured. Actually, the normal correction, which is but one of several that are made, is not a function of latitude at all. More serious is the description of the gravity pendulum as a plumb bob deflected from the vertical by the horizontal pull of high density masses.

Petroleum Geology deserves particular commendation for 1) its many fine illustrations, carefully conceived and artistically executed; 2) for its wealth of references, which completely document every facet of the discussion and indicate an amazing familiarity with the literature on the part of the author; and 3) for the informal style of writing which keeps the material interesting in spite of a mass of facts and data that in the hands of a less skilled author would consign the book to dusty reference shelves. In this reviewer's opinion, it will be the definitive textbook on petroleum geology for some time to come.

MILTON B. DOBRIN
Magnolia Petroleum Company

The Extrapolation, Interpolation and Smoothing of Stationary Time Series, by N. Wiener, John Wiley and Sons, Inc., New York, 1949, 163 pp., $4.00.

This book is in large part a reprint of the NDRC Progress Report No. 19 to the Services prepared by Professor Wiener in 1941–1942. This is the report that occasioned the notorious open letter[1] in which Professor Wiener strongly proscribed research on guided missiles and other military problems.

The purpose of the book is fully described by the title. The expression "stationary time series" is defined on pages 17 and 18. An approximate definition is that a time series is stationary if an auto-correlation function exists. For example if the time series is an infinite sequence of values $\cdots$, a_{-n}, $\cdots$, a_0, $\cdots$, a_n, $\cdots$ (which may be complex) the auto-correlation function is defined as

$$\lim_{N\to\infty} \frac{1}{2N+1} \sum_{n=-N}^{+N} a_{n+k}\bar{a}_n. \tag{1}$$

A stationary time series is one for which this series exists for all values of k. The bar denotes the com-

[1] N. Wiener, "A Scientist Rebels," *Atlantic, vol. 179* (January 1947), 46.

plex conjugate. An auto-correlation function can be defined for a continuous series of data by changing the summation in (1) to an integral as in (4).

The twenty-four page introduction is a readable summary of and guide to the remainder of the book. Chapter I is a "Résumé of Fundamental Mathematical Notions." The advice of the author is "for the reader who first approaches the subject to use it [Chapter I] for purposes of reference only, and proceed directly to Chapter II." This is excellent advice. The two mathematical disciplines that are used repeatedly in the book are complex function theory and Fourier Integral theory.

The central problem of the book is set forth and solved in Chapter II. The problem is: Given a continuous time series $f(t)$ which is known for the present and all past time, what treatment should be applied to this information in order to arrive at the best estimate of the value $f(t+\alpha)$ of the time series at a period of α units of time later? The permissible operations on the available information can be characterized by a Stieltjes integral

$$\int_0^\infty f(t-\tau)dK(\tau) \tag{2}$$

where $K(\tau)$ is a linear operator of finite total variation. The criterion by which the optimum choice of $K(\tau)$ is reached is that

$$\lim_{T\to\infty} \frac{1}{2T}\int_{-T}^{T}\left|f(t+\alpha)-\int_0^\infty f(t-\tau)dK(\tau)\right|^2 dt \tag{3}$$

shall be a minimum; that is, the predicted value will agree with the true value in the sense of the method of least squares. Wiener shows that (3) has a true minimum and that the lower bound for this minimum depends only on the auto-correlation function $\phi(\tau)$ defined as

$$\phi(\tau) = \lim_{T\to\infty} \frac{1}{2T}\int_{-T}^{T} f(t+\tau)\overline{f(t)}dt. \tag{4}$$

The analysis shows that (3) has a minimum when $K(\tau)$ is the solution of a Wiener-Hopf integral equation of the first kind, Eq. (2.0207). The function $K(\tau)$ is replaced by a transform $(k\omega)$, the optimum value of which is given in Eq. (2.041). The resulting function $k(\omega)$ can be used directly to specify the characteristic of an electrical network or mechanical system to accomplish the work of prediction. The mean square error defined in (3) is evaluated in Eq. (2.042) for the optimum filter design.

A significant feature of the solution of the prediction problem is that the optimum treatment of the data depends only on the auto-correlation function $\phi(\tau)$ and not on the individual message. Thus when one filter has been designed, it can be used on all messages which have the same auto-correlation function.

The problem of prediction is important in many branches of geophysics, such as meteorology, but it is not the significant problem in seismic prospecting. The output of the geophone consists of the sum of a message $f(t)$, the reflections, and a disturbance $g(t)$, such as ground roll. The problem in the design of seismic instruments is the determination of the "linear operator, which when applied to $f(t)+g(t)$, will give us the best approximation to $f(t+\alpha)$." If the problem is solely one of filtering and not of prediction, then negative values of α are permissible. It is shown by Wiener that in the later case the filtering action improves as $\alpha\to-\infty$.

The problem of designing a filter for the purpose of separating a message from noise is solved in Chapter III. The problem of designing the optimum filter is replaced by the problem of finding the linear operator $K(\tau)$ that will minimize

$$\lim_{T\to\infty} \frac{1}{2T}\int_{-T}^{T}\left|f(t+\alpha)-\int_0^\infty [f(t-\tau)+g(t-\tau)]dK(\tau)\right|^2 dt. \tag{5}$$

It is shown that the design of the optimum filter depends on the auto-correlation functions $\phi_{11}(\tau)$ of the message and $\phi_{22}(\tau)$ of the noise as well as the cross-correlation function

$$\phi_{12}(\tau) = \lim_{T\to\infty} \frac{1}{2T}\int_{-T}^{T} f(t+\tau)\overline{g(t)}dt. \tag{6}$$

When the cross-correlation function is zero, the minimum value of (5) that is reached when $\alpha = -\infty$ is

$$\frac{1}{2\pi}\int_{-\infty}^{+\infty} \frac{\Phi_{11}(\omega)\Phi_{22}(\omega)}{\Phi_{11}(\omega) + \Phi_{22}(\omega)}\, d\omega. \tag{7}$$

Here $\Phi_{ii}(\omega)$ is the Fourier transform of $\phi_{ii}(\omega)$.

If one is not interested in prediction but is interested in negative α, the solution for $K(\tau)$ that results from the minimization of (5) cannot be realized practically except to some approximation. This is most unfortunate, and, consequently, the design of the filter will require nice judgment so that the errors due to finite α will be of the same size as the errors that result from the approximation to the optimum linear operator.

In order to apply these methods to the design of seismic instruments it is necessary to know the auto- and the cross-correlation functions for the sequence of reflections and for the ground motion. It would be interesting and perhaps profitable to design a filter by Wiener's theory and to compare the result with the filters in actual use. The general remarks in Section 3.0 "Formulation of the General Filter Problem" are interesting and lead one to expect that a filter designed on the principles of this Chapter will agree surprisingly well with the practical results that have been obtained by trial and error. For example Professor Wiener says that "we eventually arrive at a filter which is essentially an instrument for the separation of different frequency ranges." This is the philosophy that guides the present design and adjustment of filters in seismic amplifiers.

The fourth and last chapter of the book contains a generalization of the material of the second and third chapters. The book contains a table of the first six Laguerre functions to 5 significant figures for a range of the argument of 0(0.01) 0.1 (0.1) 18.0 (0.2) 30.0. Finally two articles by Norman Levinson are reprinted from the *Journal of Mathematics and Physics*. These articles consist of simplified presentations of the theory contained in the book.

C. W. HORTON
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Geography in the Twentieth Century, edited by Griffith Taylor, The Philosophical Library, Inc., 1951, 630 pp., $8.75.

This volume, edited by Professor Griffith Taylor of the University of Toronto, is called to the attention of the geophysical profession as an outstanding geography book. However, the term "geography book" should not carry the connotation of the geography book which the geophysicists used in grade school. The term, as developed in this book, means more the integration of the usual components of geography into a single unit in which human ecology, philosophy, and geopolitics are stressed as the focal theme of the entire volume. This unity of purpose is successfully achieved even though it is written by twenty specialists and divided into three parts, namely, Evolution of Geography and Its Philosophical Basis, The Environment as a Factor, and Special Fields of Geography. The specialists are prominent authorities in the various branches of geography from several countries including the United States, Canada, Czechoslovakia, England and Poland. The editor, Professor Taylor, opens the preface with the sentence, "So far as I am aware no book in English has yet been published which covers the ground exploited in the present volume." The reviewer, after reading this book, cannot take issue with the editor regarding this statement.

Although the book as a whole is recommended to the geophysicist for general background reading, there are certain chapters in which information is contained that he can use to good advantage in taking into consideration such geographical factors as climate, soil conditions, and meteorology in the preparation and planning of geophysical surveys on a worldwide basis. More specifically, these chapters include Geographical Aspects of Meteorology, Climatic Influences, Soils and Their Geographical Significance, and Geography and the Tropics.

The book concludes with a concise glossary of geographical terms which in itself represents an outstanding contribution toward bridging the gap between modern geography at its best, as compared with the "geography book" which all of us studied many years ago.

R. A. GEYER

"Ur- und Neuozeane" ("Primordial and Recent Oceans") by Hans Stille. (Abhandlungen der Deutschen Akademie der Wissenschaften zu Berlin Math.-naturw. Kl., Jahrgang 1945/46, Nr. 6). 68 pages, 2 plates, 4 figures, Ladenpreis 7.— DM. Akademie Verlag Berlin.

This book represents another contribution to the literature on the problem of the permanence of continents and ocean basins Stille attacks this problem primarily from the standpoint that the existing world oceans can be categorized into Urozeane and Neuozeane. On the basis of criteria which include special geotectonic considerations and historical geological evidence, as well as the structure and volcanic characteristics of the marginal areas of the present oceans, he classifies them into five primordial and one recent ocean. Those included in the first category are the Pacific and Arctic and the Atlantic Oceans, with the Atlantic subdivided into a Northern and Southern Branch, and a transition zone. The Indian Ocean is the only one definitely classified in the recent ocean category. The areal distribution of these different types of oceans and their basic components together with a number of transition types, as well as the land mass counterparts, are presented in color on two large maps. One map is entitled "A Geotectonic Map of the Atlantic Area" and the other of the Arctic. No reference is made to the Antarctic Ocean as such, but this body of water is divided between the present Pacific and South Atlantic oceans and a transition type called the Weddell Sea.

The arguments and evidence used in the development of his theories are entirely of a geologic and oceanographic nature. It is difficult to understand how such broad generalizations on such a fundamental topic can be made entirely along such lines of evidence, ignoring completely the available geophysical evidence. In this connection, a paper by Jeffreys, presented at the International Society of Geodesy and Geophysics at the Edinburgh meeting in 1936, is recommended to fill in this very obvious gap. It is entitled "The Problem of Oceanic Structure." The available seismic, gravity, geothermal, and geochemical information is aptly summarized. This approach to the problem which Stille sets out to solve is very pertinent. In addition, the information available in subsequent publications by Jeffreys, Ewing, Bullard, Griggs, Hess, Kuenen, and Shepard, published since 1936, should add immeasurably to an understanding of the limitations and potentialities of Stille's relatively recent excellent summary of the geological and oceanographic evidence pertinent to the problem of the permanence of continents and ocean basins.

R. A. GEYER

"Ergebnisse der Beobachtungen am Adolf-Schmidt-Observatorium für Erdmagnetismus in Niemegk in den Jahren 1939–1944. 1. Teil: Stunden-, Tages-, Monats,- und Jahresmittel der erdmagnetischen Elemente" (Observations at the Adolf-Schmidt-Observatorium at Niemegk for Geomagnetism for 1939–1944. Part I: Hourly, Daily, Monthly and Annually Average Values of Geomagnetic Characteristics) by G. Fanselau. 114 pages, Academie-Verlag, Berlin.

This book consists primarily of tables on earth magnetic characteristics observed at the Niemegk Observatory for the period 1939–1944. It is interesting to note that the observations can be compared to a certain extent with corresponding meteorological data. The accompanying text is just long enough to explain the tables. The chief value of this book lies more in the field of ionosphere research, although it is possible that some geophysicists could use the information contained therein in studying the propagation of electromagnetic waves in connection with certain electrical prospecting methods.

R. A. GEYER

"Die jungalgonkische Regeneration in Raume Amerikas" ("Early Algonkian Regeneration in the Western Hemisphere") by Hans Stille. (Abhandlungen der Deutschen Akademie der Wissenschaften zu Berlin, Math.-naturwiss. Klasse, Jahrgang 1948, Nr. 3) 39 pages with 12 figures, Ladenpreis 5.25 DM. Akademie-Verlag, Berlin.

The significance of the problems involved in this paper by Stille should be realized by all geologists and geophysicists working in this hemisphere. His approach is entirely on the basis of available geologic evidence which he synthesizes in a very admirable manner. However, the reviewer after read-

ing this paper is struck by the complete absence of any geophysical evidence, with the exception of an early paper by Hess dealing with the Navy-Princeton gravity expedition to the West Indies in 1932. To those particularly interested in the geology and geological history of the Gulf of Mexico and Caribbean area, some of the figures presented dealing with the origin of the major geological constituents of these areas should prove to be of considerable interest. They offer a fresh approach to the problem, particularly to those whose knowledge of the subject is confined primarly to Schuchert's work in this area. Stille's seven point comparison of the causal relationships between the geotectonic characteristics of the Gulf of Mexico and Caribbean Seas with the Falkland Island reentrant constitute an excellent summary and evaluation of this problem.

R. A. GEYER

"Eine Induktions-Impulsmethode für den Nachweis des Erdöls," by Max Müller. (An Induction Pulse Method for Detecting Petroleum)—*Geofisica Pura e Applicata*, Vol. *17*, 56–61 (1950).

After a brief review of the nature of relaxation processes in molecular systems, the author states that the conductivity and dielectric constant of earth materials vary with frequency. The variation in conductivity he indicates as fifty-fold in the frequency range from 20 to 10,000 c.p.s. On the basis of this, he develops, qualitatively, a theory for a relaxation phenomena in the ground. Most of the remaining part of the paper is then devoted to a schematic discussion of feedback arrangements in resonance circuit amplifiers as a means of detecting these relaxation times. Although there is no specific description of the other apparatus, it seems apparent that two coils oriented with their axes perpendicular to each other are used. One becomes the exciter and the second the detector. The resulting data used are the relaxation times measured at various locations. Finally, a set of contours of equal relaxation time are presented without any further description. It is claimed that these contours (which resemble two nearly circular low closures very close to each other) represent two petroleum deposits at a depth of about 2,100 feet. Then the statement is made that the method is applicable for petroleum prospecting at depths greater than 6,000 feet.

There is no attempt to disclose the method of measurement. As a result, it is difficult to visualize just what these results mean. The field results are simply given without identification or discussion. Hence, while it may be true that relaxation phenomena exist in earth materials, this paper gives no proof that such a phenomenon is measured. Finally, on the basis of most reports of carefully measured conductivities, this reviewer has never seen any evidence of such a large variation of conductivity with frequency. On the other hand, it is very easy to obtain *apparent conductivities* which do vary with frequency and which can be misinterpreted as *true conductivities*.

W. JACQUE YOST
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"Les sismographes electromagnetiques et l'enregistrement conforme des mouvements du sol," by M. T. Antunes, *Boletin da Sociedada Portuguesa de Ciencias Naturais*, Vol. 18, Series 2a, pp. 66–84, 1950.

Antunes observes correctly that it is of paramount importance in earthquake seismology to observe the first arrival of any wave emanating from a distant epicenter with a high degree of fidelity with regards to both amplitude and phase. Since the predominant periods of the first-arrival-waves lie between 0.2 and 5 seconds, it was only natural that the paper by D. P. Kirnos and N. V. Veshniakov (1) which describes a seismograph for just such applications, attracted his attention. Basing himself on a brief abstract (2) of this paper, he proceeded with an analysis of the Kirnos seismograph which constitutes an excellent piece of painstaking "detective work."

It might be well to restate the so-called Galitzin condition: namely, the two movable systems, the seismometer and the galvanometer, are to be adjusted in such a manner that their natural undamped periods and their damping constants are equal. It is, known today however, that considerable deviation from this condition is required, depending upon the nature of the investigation. (For example, in petroleum exploration, the galvanometer period should be much shorter than the seismom-

eter period.) Furthermore, the reaction of the galvanometer motion on the seismometer motion is of great importance (3) and is not considered either by Galitzin or by Antunes. The performance of the Galitzin seismograph is, nevertheless, regarded as a standard in earthquake seismology.

Starting from basic physics, Antunes calculates the induced EMF and the current flowing (4) in the system as a result of sinusoidal forced vibrations. He then assumes a light ray incident on the galvanometer mirror and writes down the two linear, second-order differential equations which govern the seismometer and the galvanometer motions. These equations are solved with omission of second-order effects and of transient terms. Then the dynamic amplification, i.e., the recorded deflection divided by the displacement of the earth, is obtained and is brought into a form constructed as follows: dynamic amplification = constant term times function of periods of earth-, seismometer-, and galvanometer-motions and damping coefficients of seismometer and galvanometer (equation 9).

This equation holds equally well for the Galitzin type and Benioff type (unbalanced reluctance detector) and should also hold for the Kirnos seismograph.

He next investigates the above equation critically by considering one portion of the function at a time and arrives at an inequality between the damping coefficient of the galvanometer and an expression involving the periods of the earth- and galvanometer-motions. If the latter is satisfied, the amplification is independent of the galvanometer period and in effect almost equals that of a pendulum which is not coupled to the galvanometer system. This is in agreement with Kirnos. If, moreover, another set of inequalities involving the seismometer system are satisfied (equations 13a and 13b), then the amplification is seen to be invariant.

Antunes next speculates on the order of magnitude of the two damped periods and the two damping coefficients of the Kirnos seismograph. From the above inequalities he shows easily that the galvanometer period should be about 1 second for an earth-motion period between 0.2 and 5 seconds. Furthermore, he concludes that the seismometer period must be very large while the seismometer damping coefficient should be smaller than 1. (This conclusion results from a clever use of a power series expansion of the main expression for amplification.) On the other hand, the seismometer damping may not be too small for, if the period of the forced motion tends to that of the seismometer period and the seismometer has zero damping, the amplification tends to infinity, a condition which is certainly undesirable. Kirnos has therefore chosen a seismometer damping of about 0.5. Finally, the inequalities in conjunction with the full expression for amplification demand that operation with extremely large galvanometer damping is essential for this seismograph. (If it is too low, then we rapidly approach the limits within which the periods of the earth's motion should lie for high-fidelity reproduction.)

Relative response curves for various numerical values serve as illustrations. For a galvanometer period of 1 second, seismometer period of 20 seconds, galvanometer damping coefficient of 10 and seismometer damping coefficient of 0.5, the response curve is particularly flat for earth motion periods between 0.2 and 11 seconds. (In view of this, the reviewer does not quite follow Antunes' statement that Kirnos must be working with a seismometer period not much larger than 10 seconds while the normal Galitzin seismograph usually employs a 13-second period for the seismometer.)

Considering the orders of magnitude for the four constants mentioned above, Antunes speculates that for the Kirnos seismograph the maximum for the variable part of the expression for amplification should be about 60 times smaller than that for the Galitzin type. This would indicate that Kirnos must overcome this loss by an enormous increase of the constant part of this equation, involving the distance from the galvanometer mirror to the recording medium, the reduced length of the sample pendulum, the strength of the magnetic fields, and the moments of inertia as well as the various resistances.

In connection with the examination of the phase difference between the motion of the earth and the displacement of the photographic image, the approximate expression does not reveal in what manner the phase angle approaches zero, as claimed by Antunes. In fact, general network theory teaches that a linear increase of phase for a region of constant amplitude gives ideal fidelity of reproduction. Having this in mind, the reviewer checked numerically the exact expression (for phase angle) as a function of the period of the earth motion and found it to be almost perfectly linear for earth-motion periods of between 2 and 12 seconds.

The reference to E. F. Savarenski (5) is a little misleading. In that paper it is merely pointed out that in the Moscow seismological station, which is not equipped with Kirnos seismographs, it is apparently necessary to adjust the constants of the three-component seismograph of the aggregate so that the corresponding constants are exactly equal while with the Kirnos seismograph such an equality is not required.

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REFERENCES

(1) "Modern Seismometric Instruments" (in Russian), *Izvestia Akad. Nauk. SSSR. Ser. Geogr. Geofiz., Vol. 12, No. 4*, Moscow (1948), 319–927.
(2) An English abstract is to be found in U. S. Geological Survey *Bulletin 959-D, Geophysical Abstracts 135*, Oct.–Dec., 1948, No. 10562.
(3) J. Rybner, "The Determination of the Instrumental Constants of the Galitzin Seismograph in Presence of Reaction," Gerland's *Beitraege zur Geophysik, Vol. 51* (1937), 375–401.
(4) The treatment is similar to that of F. Wenner "A New Seismometer Equipped with Electromagnetic Damping and Electromagnetic and Optical Magnification," Bureau of Standards, *Journal of Research* (1929), 963–999.
(5) An English abstract is to be found in U. S. Geological Survey *Bulletin 959-D, Geophysical Abstracts 135*, Oct.–Dec., 1948, No. 10579.

"The British Submarine Gravity Surveys of 1936 and 1946" by B. C. Browne and R. I. B. Cooper, *Phil. Trans. of the Roy. Soc. of London, Series A., Mathematical and Physical Sciences #847, Vol. 242, 9 Feb. 1950*, pp. 243–310.

Gravity observations at sea made on board *H.M.S. Narwhal* in 1938, interrupted by the commencement of the second World War, were completed in 1946 on board *H.M.S. Tudor*. The apparatus was that borrowed from Vening Meinesz and included the long period pendulum apparatus constructed by Vening Meinesz to observe the necessary quantities to make the second order corrections. The need for those corrections was pointed out by B. C. Browne in an earlier paper. Vening Meinesz has published the details of both sets of apparatus. Timing was accomplished with crystal controlled chronometers accurate to about 1 part in a million.

On *H.M.S. Narwhal* additional observations of the residual accelerations of motion were attempted. A horizontal cantilever spring loaded at one end and damped by a vane in an oil bath was used to observe the vertical accelerations. The difference in deflection between two damped pendulums of periods 0.3 sec and 30 sec was used to measure the horizontal accelerations. This apparatus was not satisfactory.

On *H.M.S. Tudor* the 30 sec damped pendulums were replaced by a gyroscope to indicate the direction of the vertical. This apparatus functioned satisfactorily except for the vertical cantilever system which developed mechanical difficulty early in the cruise and could not be remedied.

On both cruises soundings were made with echo sounders. Navigation was accomplished principally by standard celestial methods supplemented on *H.M.S. Tudor* by Loran.

On *H.M.S. Narwhal* three sea observations and one observation alongside the dock in North Yard at Devonport were made. Base station observations were made before and after the cruise at the Pendulum House, Cambridge, where a gravity value of 981.265 cm/sec^2 was adopted. Three base observations were made before the cruise which showed a maximum variation for pendulum 88 equivalent to 1.3 milligals and for pendulum 90 equivalent to 1.2 milligals. Three base observations were made after the cruise which showed a maximum variation for pendulum 88 equivalent to 1.5 milligals and for pendulum 90 equivalent to 2.3 milligals. The difference in the mean periods before and after the cruise was equivalent to +0.6 milligal for pendulum 88 and −1.9 milligals for pendulum 90.

On *H.M.S. Tudor* 51 sea stations were occupied as well as observations in port at Portland, Falmouth,

and Oban. Base station observations were again made at the Pendulum House, Cambridge using the same gravity value. The maximum variation of the five base observations before the cruise was 1.4 milligals for pendulum 88 and 3.1 milligals for pendulum 89. The maximum variation of the three base observations after the cruise was 1.4 milligals for pendulum 88 and 2.1 milligals for pendulum 89. The difference in the mean periods for before and after the cruise was equivalent to +1.6 milligals for pendulum 88 and −2.2 milligals for pendulum 89.

The authors estimate the accuracy (r.m.s. error) of the base station observations at about 0.5 milligal, and for the sea station observations at ±3.5 milligals (r.m.s.) or 2.5 milligals (probable error).

The horizontal accelerations measured by the Vening Meinesz apparatus and that of the authors show a discrepancy greater than can be accounted for by the known sources of error. This divergence is left without explanation and the measurements of the authors' apparatus are used except where the Vening Meinesz apparatus furnished the only available data. In all cases horizontal and vertical accelerations were assumed equal.

Free air and modified Bouguer anomalies were calculated for all stations using densities of 1.03 for the water and 2.67 for rock. Isostatic anomalies were calculated according to the following nine systems: 1) Hayford, depth of compensation 113.7 km; 2) Heiskanen, T=20, R=0; 3) Heiskanen, T=20, R=58; 4) Heiskanen, T=20, R=174; 5) Heiskanen, T=30, R=0; 6) Heiskanen, T=30, R=58; 7) Heiskanen, T=30, R=174, Heiskanen, T=30, R=232; 8) Heiskanen, T=40, R=0; and 9) Heiskanen, T=60, R=0.

A correction for the sediment depths was made on the profile, which followed the seismic profile of Bullard and Gaskell.

The observations were made along profiles from Portland, England to sea along a southwest course, from Falmouth, England on a south course to the coast of Spain, from the 1,000 fathom curve southwest of Falmouth northwesterly parallel to the main axis of Great Britain, thence to the northwest coast of Scotland, and from the northwest coast of Scotland back to Falmouth. The observation interval varied from about 40 miles to about 120 miles. Charts of the free air anomalies, modified Bouguer anomalies, Heiskanen anomalies for $T=30$ and $R=58$ km are shown. On the southerly observations a chart of the Heiskanen anomalies for T=30 and R=174 is shown. For the coast of Scotland a chart of the Heiskanen anomalies for T=30, R=58 km is also shown.

The authors conclude that:

1. The echo sounding records show very rugged submarine topography, probably due to submarine canyons at the edge of the continental shelf.
2. Gravity values show the area has a mean positive anomaly. In the shallow water of the English Channel the scatter in values is similar to that found on land. In the deep water area the scatter is greater. Confirmation of the increase of isostatic anomaly on crossing the edge of the continental shelf is obtained. A wedge-shaped body of sediments of density 2.3 would almost account for this.
3. Rockall Bank and Porcupine Bank are nearly in isostatic equilibrium.
4. Three observations in the center of the English Channel show negative anomalies. Although the evidence is scanty, a considerable thickness of sediments in these areas is indicated.

This is an important paper which can only be criticized for the wide spacing of the observations, particularly in the crossings of the continental slopes. Although the difficulty of making gravity observations at sea is recognized by all, the gravitational study of the coastal margins of Great Britain could probably have been better executed by concentrating the same number of observations on two profiles. The relation of the vertical accelerations to the horizontal accelerations of the submarine due to the waves is still an open question.

J. LAMAR WORZEL
Lamont Geological Observatory
(Columbia University)

PUBLICATIONS RECEIVED

Listed below are all publications received at the business office of the society on subscription and through free exchange for *Geophysics* since publication of the last issue. Periodicals and separates indicated by the asterisk (*) have been forwarded to the Standing Committee on Reviews, and will be placed in the permanent depository of the society at the University of Tulsa Library. These publications are available for loan to members of the society on application to the business manager. Other publications will be held for a short time at the business office. Disposition of books listed is by direction of the Standing Committee on Reviews.

Periodicals

**American Journal of Science*, Vol. 249, No. 3 (March, 1951)
**Annales de Geophysique*, Vol. 6, No. 4 (Oct.–Dec., 1950)
**Annali di Geofisica*, Vol. 3, No. 4 (October, 1950)
**Az Allami Foldmeres Kozlemenyei*, Vol. 1, No. 3 (1949)
**Boletin de la Asociacion Mexicana de Geologos Petroleros*, Vol. 2, No. 10 (Oct., 1950)
**Boletin de Cienca y Tecnologia*, No. 3
Bulletin of the AAPG, Vol. 35, Nos. 2, 3 & 4 (Feb.–Apr., 1951)
**Bulletin of the Geographical Survey Institute* (Chiba, Japan), Vol. 1 (1948), Vol. 2 (1950)
**Bulletin de l'Institute Oceanographique*, Vol. 21, No. 12 (1950)
**Canadian Geophysical Bulletin*, Vol. 4, No. 3
**Articles on Geophysics in Current Russian Periodicals*, List No. 30 (1 Feb. 1951)
**Deutsche Hydrographische Zeitschrift*, Vol. 3, No. 5/6 (1950)
Economic Geology, Vol. 46, No. 2 (Mar.–Apr., 1951)
**Erdol und Kohle*, Vol. 4, Nos. 1, 2 & 3 (Jan., Feb. & Mar., 1951)
**Geofisica Pura e Applicata*, Vol. 17, No. 3–4 (Oct.–Dec., 1950)
**Gerlands Beitrage zur Geophysik*, Vol. 61, Nos. 1, 2 & 3 (1945, 1949 & 1950)
Institute of Petroleum Review, Vol. 5, Nos. 50 & 51 (Feb. & Mar., 1951)
**Jesuit Seismological Association—Commemorative Volume 1925–1950*
Journal of Applied Physics, Vol. 22, Nos. 2, 3 & 4 (Feb., Mar. & Apr., 1951)
Journal of the Institute of Petroleum, Vol. 37, Nos. 325 & 326 (Jan. & Feb., 1951)
**Nafta*, Vol. 7, No. 1 (Jan., 1951)
**Nuclear Science Abstracts*, Vol. 5, Nos. 3–7 (Feb. 15–Apr. 15, 1951)
**Proceedings of the Cambridge Philosophical Society*, Vol. 42, No. 2 (Apr., 1951)
**Quarterly Journal of the Geological Society of London*, Vol. 106, No. 1 (Dec. 28, 1950)
Review of Scientific Instruments, Vol. 22, Nos. 2 & 3 (Feb. & Mar., 1951)
**Revista de Ciencias*, Vol. 12, No. 471–472 (1950)
**Revista di Geofisica Applicata*, Vol. 11, No. 2 (1950)
**Rocznik Polskiego Towarazystwa Geologicznego*, Vol. 19, No. 4 (1949)
**Technical Data Digest*, Vol. 16, Nos. 3, 4 & 5 (Mar., Apr. & May, 1951)
**Tellus*, Vol. 2, No. 3 (Nov., 1950)

Books

Hager, *Practical Oil Geology*, 5th ed. 1938, McGraw-Hill
Ladoo, R. B. & Meyers, W. M., *Nonmetallic Minerals*, 2nd rev. ed. 1951
Pugh, W. E. & Preston, B. G., *Bibliography of Stratigraphic Traps*, 1951, Seismograph Service Corp

DISCUSSIONS AND COMMUNICATIONS

SEISMIC SOUNDINGS OF GLACIERS

Because of the ever-expanding field of activity of the geophysicist and the important contribution that can be made by seismic techniques to research in the polar regions, it is felt that the material contained in the review of the activity of the Swiss Glacier Commission, published in 1948, should be brought to the attention of American geophysicists. I have therefore prepared the following condensed translation of the paper by A. Renaud and P. L. Mercanton. I feel from experience gained in the Antarctic and on Taku Glacier (Alaska) that with the recent developments in modern portable electronic seismographs more reliable information can be obtained with these units using air shooting and at no increase in weight even for a 12-channel unit.

LES SONDAGES SISMIQUES DE LA COMMISSION HELVÉTIQUE DES GLACIERS (Seismic Soundings of the Swiss Commission of Glaciers) by A. Renaud and P. L. Mercanton (Lausanne). Publications du Bureau Central Seismologique International, Travaux Scientifiques, Serie A. Fascicule 17, Communications presentées a la conférence de Union Geodesique et Geophysique Internationale d' Oslo, August 1948.

I. INTRODUCTION

Geology, geophysics and the engineering profession are interested in the thickness of glaciers and the configuration of their beds from both a scientific and economic standpoint and this is one of the principle concerns of the Swiss Glacier Commission (C.H.Gl). Before outlining their contribution, we shall give a brief summary of previous work.

II. MECHANICAL SOUNDINGS

As early as 1842 the Swiss Agassiz succeeded in drilling a hole 210 feet deep in Lower Aar Glacier (Unteraar) without reaching bottom. Between 1895 and 1909 Hess and Blumcke drilled eleven holes to the bed of Hintereisferner (Austrian Tyrol) to depths of 215 to 730 feet and determined internal temperatures, etc., and working independently, C. Dutoit and P. L. Mercanton attempted drilling at Trient Glacier (Switzerland), and the French Administration of Waterways and Forests drilled Tête-Rousse Glacier (Mont-Blanc).

Thermal drilling by electrical heating was attempted about 1900, but Calciati (Italy) during the last war, using hot water, drilled 390 feet to the bed of Hohsand Glacier at 3 to 4 meters per hour.

III. ATTEMPTS AT PHYSICAL INSTRUMENTATION

Because of obvious disadvantages of mechanical soundings, Mercanton of the C.H.Gl in 1926 unsuccessfully attempted seismic and supersonic methods, but the following year Mathes of the Geophysical Institute of Göttingen succeeded in applying seismic methods to the Hintereisferner Glacier (Austria) with good agreement with the borings of Hess and Blumcke and subsequently on Pasterze (Austria) and Aletsch Glacier (Switzerland). In 1929 he supplied A. Wegener the seismic equipment with which he made his measurements of the Greenland ice-cap in 1929 and 1930, obtaining ice thicknesses of as great as 8,860 feet.

In collaboration with Mathes the C.H.Gl in 1931 made a study of the Rhône Glacier (Switzerland) with such good results that they adopted this method.

IV. THE SEISMOGRAPH OF THE SWISS COMMISSION ON GLACIERS

Professor A. Kreis constructed a portable seismograph for C.H.Gl well adapted to glacier studies and weighing only 27 pounds. This three-compartment single-channel mechanical seismograph had an amplification of 30,000 and the timing lines were produced by a helium tube controlled by means of a 50-cycle tuning fork.

The natural frequency of this instrument was about 20 cycles, and was dependent upon the amplification selected. The records obtained indicate a frequency range from 30 to 50 cycles. The total

weight, including explosives for a twenty-day expedition, is about 1,300 pounds. The equipment was tested on the Rhône Glacier in 1935 and has been used on all subsequent C.H.Gl seismic expeditions.

V. SOUNDINGS ON THE LOWER AAR GLACIER (UNTERAAR)

The Aar Glacier in the Bernese Alps forms the source for an artificial lake for a hydroelectric plant, and although it ranks fourth in size, it is the most important glacier in Switzerland and has been the most extensively studied for more than a century, which studies have included the important work of Louis Agassiz and his colleagues, Dollfuss-Ausset and the Oberhasli Motor Power Company. The first C.H.Gl expedition took place in 1936 on the lower glacier where the P wave velocity was 12,150 feet per second as compared with 11,820 feet per second on the Rhône Glacier. The second expedition in 1937 was on the higher glacier where the velocity was 12,480 feet per second and was devoted to the determination of the thickness of the ice and the underlying alluvial deposits.

During the first part of the third season the fluvio-glacial alluvia and the morainic deposits of the Aarboden Glacier were studied obtaining only partial agreement with the electrical prospecting of W. Fisch (Zurich) which may be accounted for by inclusions of "fossil ice." Later in the season better results were obtained farther up the glacier with nearly 1,000 feet of ice on solid rock.

The Fourth expedition in 1939, working in the Abschwund region where the Lauteraar and the Finsteraar unite to form the Unteraar, velocities of 12,600 feet per second and depths of 1,460 feet were obtained. Shear wave velocities of 5,580 feet per second were obtained and surface waves were recorded but not used.

The World War then interrupted the work until 1947 when two affluents up-stream from Abschwund were studied, the maximum depths being 1,640 feet.

In 1948 soundings were made between the upper and lower Brandlamm. The analysis of these data is under way and it is expected that interfaces between ice, sub-glacial morainic deposits and solid rock can be obtained.

In all, 750 soundings have been made on the Unteraar including both longitudinal and transverse profiles on the lower four and one-half miles of the glacier where the top surface has a slope of about 8 per cent and the bottom interface is nearly level.

VI. SOUNDINGS OF THE MORTERATSCH GLACIER

Because of the war, the C.H.Gl transferred its activities in 1943 from the lower Aar Glacier to the Bernina massif (Grisons) where one hundred soundings were made on the glacier and eighteen on the moraine downstream, in which the respective velocities were 12,000 and 5,260 feet per second and in which the corresponding average depths were about 360 and 33 feet. However, at three miles up the glacier a depth of 1,200 feet was obtained.

VII. SOUNDINGS ON THE PLAINE MORTE GLACIER

Kreis used the C.H.Gl instruments in 1946 and made a survey of the glaciers of the Plaine Morte and Wildstrubel (Bernese Oberland) for a public utilities corporation who were considering tapping the waters under these glaciers. This ice field has an altitude of over 9,000 feet and remains snow-covered throughout the summer, necessitating burying the charges two meters instead of the customary one meter.

VIII. SOUNDINGS FROM GLETSCHBODEN TO THE RHÔNE GLACIER

This study was made late in the 1949 season of the thickness of the fluvio-glacial and morainic deposits from where the glacier has been receding since 1856. Soundings indicate that the rock beds formed an elongated basin 1,500 by 300 feet.

IX. SOUNDINGS OF THE GREAT ALETSCH GLACIER

In 1947 the C.H.Gl lent their instruments, together with some financial support, to Haefeli of Zurich for the purpose of resurveying that portion of the Great Aletsch Glacier surveyed by the Göt-

tingen geophysicists in 1929. Although the records were not too good, the depths were found to be much less than the values obtained in 1929.

During the summer of 1948 West Switzerland Power Company (EOS) using fifteen holes drilled through the Gorner Glacier and a thousand seismic soundings were able to prepare a general map of that extensive glacier bed. EOS has conducted similar surveys at the Tsigiorenouve Glacier as have the British Seligman-Perutz expedition on the Jungfraufirn. With a 12-kw heating element drilling rates of as much as 80 feet per hour have been obtained.

The Swiss Commission of Glaciers (C.H.Gl) have obtained good results with this seismic method, and they plan to continue on the Aletsch Glacier particularly in the region of the névé in the vicinity of the Jungfrauhoch Station for scientific research as well as on the heights of the Finsteraar affluent.

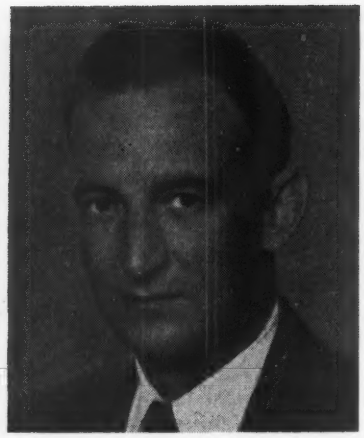
THOMAS C. POULTER
Stanford Research Institute

ERRATA

A typographical error appears in Table 3 of the paper "Electric Logging Applied to Groundwater Exploration" by P. H. Jones and T. B. Buford which appears on page 121 of the January, 1951 issue of *Geophysics* (Volume XVI, No. 1). The corrections are as follows:

As published		*Should read*	
Passed by screen opening (inches)	Retained by screen opening (inches)	Passed by screen opening (inches)	Retained by screen opening (inches)
0.0198	0.0716	0.0198	0.0176
0.0716	0.0614	0.0176	0.0164
0.0614	0.0138	0.0164	0.0138

CONTRIBUTORS



CARL L. BRYAN

CARL L. BRYAN was born in Guadalupe County, Territory of New Mexico, on August 10, 1908. Three years of undergraduate work in electrical engineering at the University of Texas were followed by employment in June 1928 in the geophysical department of Gulf Production Company at Houston. He was transferred to Shreveport, Louisiana in 1930 as assistant torsion balance supervisor. From 1932 to 1942 he served various divisions and affiliates of the Gulf Oil Corporation in numerous capacities on torsion balance, pendulum, gravimeter and seismograph field crews on domestic and foreign assignments.

He entered the U. S. Navy in 1942, served three years aboard aircraft carriers in the Pacific Ocean Area, during which time he attained the rank of Lieutenant Commander, and was transferred to inactive duty in January 1946, at which time he rejoined the Gulf organization. Shortly thereafter he was assigned his present position as chief geophysicist for Gulf Refining Company at Shreveport. In 1950 he received the B.S. degree in geology from Centenary College of Louisiana.

He is a member of the Society of Exploration Geophysicsts, American Association of Petroleum Geologists, American Geophysical Union, Ark-La-Tex Geophysical Society (Past President), Shreveport Geological Society, and Sigma Gamma Epsilon, honorary geological fraternity.

KARL DYK

KARL DYK received his B.S. degree from the University of California at Berkeley in 1930 and his Ph.D. degree in seismology from the same institution in 1934. From 1933–35 he was engaged in the Submarine Acoustic Research for the U. S. Coast and Geodetic Survey. During his work for the Coast and Geodetic Survey, he was the first to recognize and investigate the properties of sound channel in sea water. In 1935 he joined Western Geophysical Company as a computer, rising shortly thereafter to the party chief of a seismic field party. In 1940 he became a seismologist for the Stanolind Oil and Gas Company. In 1945–47 he acted as a Division Seismograph Supervisor and in 1947 became Chief Geophysicist, which position he holds at the present time. He is a member of American Geophysical Union, Seismological Society of America, Society of Exploration Geophysicists, American Association of Petroleum Geologists, and Fellow of Geological Society of America.

J. D. EISLER

J. D. EISLER received the B.S. degree at the Massachusetts Institute of Technology in 1932. From 1932–35 he was engaged in research at the Institute dealing with the Thompson effect in metals. From 1935–36 he was employed by the Geophysical Department of the Massachusetts Institute of Technology and was instrumental in the design of three-component seismograph stations for quarry blast work. In 1936 he joined the research staff of the joint laboratories of the Western Geophysical Company and the Stanolind Oil and Gas Company. During the war, he became a member of the staff of the Franklin Institute at Philadelphia doing defense work in connection with the aircraft to aircraft fire control—a section of National Defense Research Committee. In 1944 he rejoined the laboratory staff of Stanolind Oil and Gas Company, Tulsa, Oklahoma, where he engaged in the instrumental research in seismic and other geophysical fields. In 1950 he became Research Section Supervisor in charge of fundamental geophysical research. He is a member of Sigma Xi, Society of Exploration Geophysicists, American Geophysical Union, and the Seismological Society of America.

THEODOR KREY

THEODOR KREY was born in Hamburg, Germany, in 1910. He studied mathematics, physics, geography and associated sciences at the Universities of Göttingen and Munich and received his master's degree. He taught for a short time and then became associated with the Seismos G.m.b.H., Hannover, Germany, in 1936, by whom he is still employed. Within the compass of refraction and reflection seismic surveys carried out by this company he was engaged in research in Northwest Germany, the Netherlands, Bavaria, Austria, Hungary and more recently in the North German Bay.

JOHN E. PALMER

JOHN E. PALMER was born July 21, 1908 in Chalmers, Indiana. He received the B.S. degree in electrical engineering from Purdue University in 1932 and completed a year of graduate work there in science, mathematics and education. From 1934 to 1937 he taught in various high schools of Texas. In 1937 he joined Humble Oil & Refining Company, doing gravity meter work until 1940 in Papua, New Guinea. He then transferred to Standard Vacuum Oil Company and spent two years in the Netherlands East Indies, also in gravity meter work. In 1942 he joined The Carter Oil Company and was transferred from the field to the laboratory in 1945. He retired from geophysical work March 30, 1951, and is now the owner of a poultry market in Tulsa, Oklahoma.

In addition, references are cited to earlier issues for the biographies of: Kenneth C. Crumrine, Vol. XV, No. 3 (July, 1950); E. A. Eckhardt, Vol. XIII, No. 4 (October, 1948); Maurice Ewing, Vol. XIII, No. 3 (July, 1948); Paul L. Lyons, Vol. XV, No. 4 (October, 1950); Frank Press, Vol. XIII, No. 3 (July, 1948); E. E. Rosaire, Vol. VI, No. 4 (October, 1941); George E. Wagoner, Vol. XIV, No. 4 (October, 1949); John H. Wilson, Vol. XII, No. 3 (July, 1947).

SOCIETY ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following candidates for membership in the society. This publication does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it to the president within thirty days. Names of the references appear in parentheses after the name of each nominee.

ACTIVE

Alvin Franklin Barker (W. B. Brinnon, R. M. Nugent, C. G. Dahm)
John Cecil Baxter (Sigmund Hammer, L. L. Nettleton, James A. Affleck)
James Bentley-Llewellyn (J. J. Jakosky, B. F. Rummerfield, Richard Williams)
John F. Blair (J. S. Welboan, Jr., R. L. Lay, A. A. Hunzicker)
Eugene Leigh Current (R. H. Tucker, R. M. Bradley, F. M. Hawpe)
David Baxter Davidson (A. E. McKay, O. C. Clifford, Jr., E. L. DeLoach)
William Bryan Fazakerly, Jr. (Dean Walling, Booth Strange, Fred DiGuilio)
Will Alex Gross (O. C. Clifford, Jr., C. H. Hightower, Fred L. Travis, Jr.)
Norman James Highfield (J. Ryan Walker, A. B. Hamil, J. R. Reeves)
Leon Alfred Kent (Roy L. Lay, A. A. Hunzicker, W. H. Gibson)
Charlton Kerr (Frank Searcy, E. L. Mount, C. K. Shepherd)
James Mason Klaasse (Dr. Roland F. Beers, Ben S. Melton, Homer Jensen)
Charles Edward Marshall (S. P. Worden)
John William Miller (W. B. Brinnon, C. G. Dahm, W. F. Lechtenberg)
Ross Smith, Jr. (D. P. Carlton, H. G. Patrick, R. E. Watson)
Albert Verne Street (H. M. Houghton, J. T. Gilliam, J. H. Guntharp)
William R. Waddell (W. E. Hollingsworth, L. G. Ellis, Leo W. Konz)
William Neill Walker (R. P. Warren, R. S. Epperson, J. A. Brooks, Jr.)
Roscoe C. Wilber, Jr. (T. I. Harkins, C. H. Broussard, C. R. Lowe)
Delmer Maurice Woods (Leo J. Peters, L. W. Gardner, Sigmund Hammer)

ASSOCIATE

William David Agerton (Sidon Harris, R. H. Dana, Jack N. Morehead)
Gerrit Bakker (A. van Weelden, V. P. Ulrich, O. Koefoed)
Addison Stewart Barker (E. E. Unger, J. B. Lovejoy, V. G. Feather)
John Heber Bell (B. H. Treybig, Jr., Roy L. Lay, M. J. Millet)
Harold George Brumbaugh (Howard E. Hopson, J. C. Waterman, Rayman S. Sturdevant)
Richard Lee Brust (Carl W. Blakey, T. A. Manhart, George W. Reed)
James Yuill Butts (Dean Walling, Chester J. Donnally, George J. Shoup)
Carlos Castillo-Tejero (John C. Hollister, Cecil H. Green, James W. Thomas)
Bill Woodrow Chronister (Lynn D. Ervin, Ray G. DeGood, E. J. Handley)
James Richard Cornell (J. C. Hoffman, E. E. Conant, Julian Smith)
Wojciech Domzalski (Robert H. Ray, Sam D. Rogers, Eugene W. Frowe)
John William Roy Crawford, III (J. A. Harris, T. B. Howes, Ralph Holmer)
Henry Hewitt Fuqua, Jr. (W. J. Harkey, L. Shock, J. Gillin)
Lloyd Eugene Gourley, Jr. (Darrell S. Hughes, L. P. Whorton, H. F. Dunlap)
S. T. Harris (C. H. Green, F. J. Agnich, P. E. Haggerty)
Henry William Heck (David M. Weber, Mark K. Butler, Victor J. Blum, S.J.)
Jasper Roger Heggblom (Leo J. Peters, Sigmund Hammer, James Affleck)
Richard Louis Hyde (R. B. Baum, L. G. Cornish, R. W. Saubert)

Clement John Kalupa (Herbert Ferber, Leo Peters, R. B. Ross)
Albert Plowman Marsh (F. F. Reyholds, H. C. Smith, E. F. Zagst, Jr.)
Howard Stuart McColl (H. W. Stoneman, G. E. Shultis, D. B. McDougall)
Donald Kenneth McIvor (H. W. Stoneman, G. E. Schultis, D. B. McDougall)
Joseph Thomas McMaster (W. H. Hawkes, H. G. Hadler, G. E. Anderson)
Loren R. Miller (Flint Agee, Wayne Denning, Don C. Short)
Michael Albert Edward Mulhall (Phil P. Gaby, G. J. Hulsewe, Robert E. Doe)
Robert Norman (R. J. St. Germain, John L. Bible, Jack B. Ferguson)
Kenneth John Parry (Harris Cox, J. P. Mason, L. J. Richards)
Donald Max Patton (W. H. Denning, Flint Agee, Don C. Short)
Jack Nathan Pierson (P. V. Hodge, Earl Thomas, J. K. Pawley)
Richard Curtis Powell (Robert Dyk, V. E. Prestine, Dean Walling)
Evald Maurice Rodin (A. B. Bryan, R. W. Gemmer, Geo. G. Walton)
Michael Ross Roop (H. J. Kidder, D. V. Bigelow, L. Castelli)
Edward H. Schwing, Jr. (H. L. Rasé, W. C. Lamb, Sigmund Hammer)
Thomas Lane Slaven (John A. Adams, E. S. Partain, James G. Jackson)
Herman Lloyd Smiers (J. A. Van Auken, G. M. Mace, Jr., A. B. Hamil)
David John Smith (Don C. Short, Wayne H. Denning, Flint H. Agee)
Richard Stokes Smith (Andrew Gilmour, Albert Taylor, William P. Lawrence)
Paul Vernal Terry (E. R. Brumbaugh, H. E. Hopson, K. S. Cohick)
Arthur Vincent Thompson (S. E. Giulio, R. F. Weichert Jr., W. L. Irby)
Arthur Bynum Tinsley, Jr. (A. N. McDowell, S. A. Lynch, T. J. Parker)
Frederick Thomas Turcotte (David M. Weber, W. Bernard Robinson, Louis W. Gardner)
Norvan Lee Wasserman (A. B. Hamil, G. M. Mace, B. K. Johnson)
Nolen A. Webb (Robert Dyk, Dean Walling, V. E. Prestine)
John Drennan Weber (C. H. Green, F. J. Agnich, P. E. Haggerty)
Chang Sheng Wu (E. Schempf, C. C. Lister, R. A. Peterson)
John Meredith Young (Henry L. Rasé, Jr., Guy I. McCracken, Sigmund Hammer)
Irving Clarence Zacher (F. Goldstone, R. D. Miller, C. H. Gregory)

Transfer to Active

B. W. Beebe (T. A. Manhart, Sidon Harris, Carl W. Blakey)
Jonathan Ewart Blanchard (A. A. Brant, John H. Hodgson, Ernest A. Hodgson)
F. W. Brown (J. T. Randell, A. A. Brant, A. G. Schlitt)
Donald Page Melton (Eugene Frowe, Sam D. Rogers, R. L. Palmer)
Russell Nelson Ostreim (Eugene Frowe, John R. Monkhouse, J. B. Nichols)
Jerzy Sosnowski (J. M. Bruckshaw, S. Wyrobek, C. Twardowski)

Transfer to Associate

Wilfred Pearsall Hasbrouck (George Dunn, John C. Hollister, Ralph C. Holmer)
Joseph W. Jackson, Jr. (Robert L. Schmidt, Jesse E. Spencer, V. A. Peterson)
John Gilbert Jaka (Harrison E. Stommel, Ralph C. Holmer, O. A. Armstrong)
Charles Raymond Jones (Edward J. Gemmill, W. T. Lea, Darrell S. Hughes)
Stephen W. Miller (Thomas C. Poulter, L. M. Swift, B. W. Sorge)

MINUTES

ANNUAL BUSINESS MEETING

April 23, 1951

The annual meeting of the Society of Exploration Geophysicists was held in St. Louis at the Hotel Jefferson on April 23, 1951. George E. Wagoner presided.

The reading of the minutes of the 1950 annual business meeting was omitted since they had been

published in *Geophysics*. Reports of the Vice President, Sigmund Hammer; Secretary-Treasurer, Francis F. Campbell; and the Editor, R. A. Geyer, were presented and are attached as exhibits A, B and C.

Reports of the following standing committees were presented.

Committee	Chairman	Exhibit
Membership	Kenneth E. Burg	D
Honors and Awards	L. L. Nettleton	E
Public Relations	Paul L. Lyons	F
Distinguished Lectures	Joseph A. Sharpe	G
Reviews	Milton Dobrin	H

The report of the Standing Committee on Geophysical Education was read by James B. Macelwane, S. J., Chairman, and copies were distributed. The report is being reproduced in the technical section of this issue. R. D. Wyckoff, Chairman of the Standing Committee on Radio Facilities, gave a brief oral report to supplement the written report which appeared in *Geophysics* for April, 1951. The report of the Standing Committee on Annual Survey of Geophysical Activity was presented by E. A. Eckhardt as the first paper of the next technical session. The president announced the results of the mail ballot for new officers:

For President:
- Sigmund Hammer (elected) 677
- Sidon Harris 383

For Vice President:
- Curtis H. Johnson (elected) 653
- W. W. Newton 395

For Secretary-Treasurer:
- E. D. Alcock 463
- R. C. Dunlap, Jr. (elected) 585

For Editor:
- Milton B. Dobrin 493
- Paul L. Lyons (elected) 544

The president announced that recommendations contained in the reports would be discussed at the council meeting on April 24.

FRANCIS F. CAMPBELL, *Secretary-Treasurer*

EXHIBIT A. REPORT OF THE VICE PRESIDENT

The principal official duty of your Vice President is to be responsible for the arrangements and program of the Annual Meeting. In discharging this responsibility during the past year I have been ably and effectively assisted by a committee of 25 members whose names are listed on page 52 in the program for the annual meeting. On behalf of the society I wish to express our sincere thanks to all these committee members for their excellent and enthusiastic work. We also wish to thank the authors of the papers for their important contributions. The fine program of papers which you will hear is entirely the result of the interest and efforts on your behalf by all these persons.

A total of 30 papers are on the SEG program. These are divided by subject as follows: Seismic—15; Gravity—6; Magnetic—2; Case Histories—2; General—5. In addition an interesting Geophysical Field Trip has been arranged, at the invitation of Father Macelwane, to the Institute of Technology at St. Louis University and the Geophysical Field Station at Florissant.

Five papers of broad geological interest, which were originally prepared or solicited under the auspices of the SEG, have been placed on the AAPG program.

Finally, I would like to make public acknowledgement of the very fine spirit of co-operation which exists between the AAPG, the SEPM, and the SEG. The officers of the three societies met several times during the past year to formulate and co-ordinate the general plans for the programs at this joint annual convention. In particular, I would like to record my especial appreciation to Mr. Clarence L. Moody, President of the AAPG; and to Mr. Walter H. Spears, chairman of the AAPG pro-

gram committee, for their wholehearted co-operation. The mechanics of our techniques may differ but our basic objectives are so closely interrelated that we may confidently anticipate a continuation of this fine spirit of co-operation in the future.

SIGMUND HAMMER, *Vice President*

EXHIBIT B. REPORT OF SECRETARY-TREASURER

The report of the Secretary covers the period from the joint Council Meeting on April 25, 1950, up to April 23, 1951. During this period the Executive Committee met once at Fort Worth on November 30. All other actions of the Society were covered by twenty-two executive orders. Eleven of these concerned membership applications. Consideration of these applications is the most time consuming duty of the executive committee.

Three executive orders concerned local sections. The meeting at Houston in May and the meeting at Fort Worth in November were approved as regional meetings The petition of the Denver section was approved. Changes in the constitution of the South Texas Geophysical Society were recommended but a revised petition has not been submitted.

Three executive orders concerned *Geophysics*. The advertising rates were raised 50 percent. From a financial standpoint this was the most important action taken. Microcards were adopted for reproducing out of print issues at a price of twenty-five cents a card.

Other executive orders approved moving the site of the business office from a downtown location in Tulsa to a suburban location. The salary of the assistant to the business manager was raised in August, 1950, from $185.00 per month to $225.00 per month in recognition of Mrs. Reames assuming the duties of bookkeeper. A contest for the design of a crest for the Society was authorized. The Association of American State Geologists was accepted as a member of the American Geological Institute. Bad debts for sale of publications of $100.00 were written off.

The Treasurer's report covers the operations for the calendar year 1950 and the estimated income and expense for 1951.

The estimates for income and expense are listed in Table I under the 1951 budget and may be compared with the actual figures for 1949 and 1950.

TABLE I

1949, 1950 OPERATIONS, 1951 BUDGET

	1949		*1950*		*1951 Budget*	
Income:						
Membership dues	$11,400		$12,500		$21,000	
Geophysics	13,300		15,700		22,000	
Geophysical Case Histories	13,300		1,500		1,000	
Cumulative Index	300		100		—	
Other income	200		300		300	
Total income		$38,500		$30,100		$44,300
Expenses:						
Operating expenses	$15,400		$16,300		$18,000	
Geophysics	13,500		15,000		17,200	
Microcards	—		200		—	
Geophysical Case Histories	12,800		—		—	
Cumulative Index	2,100		—		—	
Total expenses		43,800		31,500		35,200
Net income (loss)		($ 5,300)		($ 1,400)		$ 9,100

The figures in Table I show that the loss of $5,300 in 1949 and of $1,400 in 1950 will be changed to net income of more than $9,000 in 1951 because of an increase in membership dues from $5 to $7.50 and a 50 percent increase in advertising rates on January 1, 1951.

The balance sheet at December 31, 1950, shows the society to be in a strong cash position. The assets are conservatively stated because the inventory of publications which has a possible sales value of $23,000 has been completely charged off. The reserves are adequate to cover operating losses over a period of several years although no losses are anticipated. The reserves are also adequate to finance the publication of a second volume of Geophysical Case Histories. The incoming officers and council have the pleasant duty of using the expected net income to increase services to the membership of the society.

FRANCIS F. CAMPBELL, *Secretary-Treasurer*

The report of the independent accountants for the year 1950 follows:

PRICE WATERHOUSE & CO.

Tulsa
April 19, 1951

To the Executive Committee,
Society of Exploration Geophysicists,
Tulsa, Oklahoma.

We have examined the balance sheet of the Society of Exploration Geophysicists as at December 31, 1950 and the statement of net loss for the year then ended. Our examination was made in accordance with generally accepted auditing standards and included such tests of the accounting records and

OFFICERS FOR THE YEAR ENDING MARCH 24, 1952

Left to right: R. C. Dunlap, Jr., Secretary-Treasurer; Sigmund Hammer, President; George E. Wagoner, Past President; Curtis H. Johnson, Vice President; Paul L. Lyons, Editor.

such other auditing procedures as we considered necessary in the circumstances except that, as instructed, we did not apply the customary procedure of confirming receivables by direct communication with debtors.

The office staff is too small to permit the establishing of an effective system of internal control, and we therefore extended our tests of the transactions beyond those necessary where an adequate system is in force. While we did not make a detailed audit of all of the transactions, we compared the recorded cash receipts in totals with deposits shown on the bank statements for the year and examined paid checks, cash vouchers, and other data in support of disbursements.

In our opinion, subject to the foregoing comments relating to receivables and to the system of internal accounting control, the accompanying balance sheet and statement of net loss present fairly the position of the society as at December 31, 1950 and the results of its operations for the year, in conformity with generally accepted accounting principles applied on a basis consistent with that of the preceding year.

PRICE WATERHOUSE & CO.

SOCIETY OF EXPLORATION GEOPHYSICISTS
BALANCE SHEET—DECEMBER 31, 1950

ASSETS

Cash		$15,973.61
Accounts receivable:		
Membership dues	$ 804.95	
Other	3,597.17	
	$ 4,402.12	
Less—Allowance for bad debts	700.00	3,702.12
Inventory of publications (see note)		—
Investment in United States Savings Bonds, at cost		13,880.00
Office equipment	$ 1,372.21	
Less—Accumulated depreciation	685.19	687.02
		$34,242.75

LIABILITIES

Accounts payable		$ 290.65
Federal insurance contributions tax		16.01
Deferred income:		
Membership dues	$13,434.45	
Subscriptions to and advertising in *Geophysics*	3,060.07	16,494.52
Surplus:		
Balance, December 31, 1949	$18,857.35	
Net loss for the year, per accompanying statement	(1,415.78)	17,441.57
		$34,242.75

Note—

The accounts do not reflect the inventory of back numbers, reprints, and microcards of *Geophysics*, the cost of which was charged off at time of original publication, or the inventory of special publications of prior years. Proceeds of sales of special publications are applied against their cost until cost is absorbed; any balance of cost is reduced to a maximum of one-half the cost of

unsold copies at the end of the year of publication and is written off at the end of the subsequent year. There were no special publications in 1950.

SOCIETY OF EXPLORATION GEOPHYSICISTS
STATEMENT OF NET LOSS
FOR THE YEAR ENDED DECEMBER 31, 1950

INCOME:			
Membership dues		$12,502.00	
Publications—			
Advertising	$9,705.30		
Subscriptions	3,402.74		
Back numbers	2,050.87		
Reprints	1,020.04		
Geophysical Case Histories, Vol. I	1,518.00		
Cumulative Index to *Geophysics*	99.30		
Discounts allowed	(450.13)	17,346.12	
Commissions on sales of books published by others		145.90	
Interest received		125.00	
			$30,119.02
EXPENSES AND PUBLICATION COSTS:			
Salaries—			
Business manager		$ 4,500.00	
Office assistant		2,400.00	
Commissions—			
Advertising—business manager		1,781.96	
Advertising—agencies		1,233.54	
Subscriptions—agencies		251.82	
Office rent		1,050.00	
Stationery and office supplies		2,282.33	
Postage		590.14	
Telephone and telegraph		376.37	
Auditing		425.00	
Depreciation of office equipment		199.29	
Advertising		205.38	
Provision for bad debts		581.30	
Federal insurance contributions tax		71.75	
Miscellaneous		355.91	
		$16,304.79	
Publication costs		15,230.01	
			31,534.80
Net loss			$ 1,415.78

EXHIBIT C. EDITOR'S REPORT

This report covers the period April 1950 through March 31, 1951, representing the second year of the present Editor's term of office. Thirty-four technical papers totaling 492 pages were included in the four issues of *Geophysics* published during this period. In addition, 48 pages of reviews and 60 pages of patents constituted the remainder of the technical material printed.

The policy pursued during the previous year, namely, to obtain papers from geophysicists outside the United States was continued as an aid in understanding and coping with geophysical problems on a global scale. A total of 6 papers by geophysicists from Canada, France, Italy, Iran, and Turkey were published.

During the past year the necessary steps were completed to make available to the Society membership, as well as other interested groups, back issues of *Geophysics* in microcard form. This material is now available at a nominal cost of 25¢ a card to those wishing to complete their file of *Geophysics*.

A major change in the method of presentation of the Patent Section was inaugurated during this period in an effort to make this valuable service available to the profession in substantially the same form as previously, but reducing markedly the number of pages which this section occupies and hence the printing cost. Only abstracts of patents dealing specifically with geophysical methods and instruments were published but, in addition, those patents which might have application either directly or indirectly at the present or at some time in the future were listed by their patent number in their proper subject classification. Thus, those in the profession who were interested could still use the Patent Section as a means of being made aware of the existence of these patents although it necessitated their referring to the *Patent Gazette* for additional details. The Editor would like to take this opportunity to again express his sincere appreciation to Mr. O. F. Ritzmann for continuing with his time-consuming and very accurate compilation of the Patent Section.

The Special Reviews Committee which received the status of a standing committee during the past year was again very active in bringing to the attention of the profession an expert valuation of a broad cross section of the diversified literature of geophysics from sources not readily available, in addition to the reviews of pertinent books which appeared during the past year. Fifty-four reviews were published during this past year with about one-half of this material originating outside the United States. The Editor would like to take this opportunity to again thank the Committee and in particular its Chairman, Dr. Milton B. Dobrin, for giving so generously of their time and effort in preparing this section of *Geophysics*.

In closing, the Editor would like to acknowledge his great indebtedness to those who have so ably assisted him during the past two years in the varied aspects involved in preparing *Geophysics* for publication, including Mrs. Wm. D. Ryan, assistant to the Editor, the members of the Standing Committee on Publications, particularly the Chairman, Dr. W. M. Rust; and Mr. Colin C. Campbell, the Society's Business Manager.

EXHIBIT D. REPORT OF THE MEMBERSHIP COMMITTEE

The Membership Committee for the term 1950–51 was composed of: Kenneth E. Burg, *Chairman*, H. M. Houghton and E. V. McCollum.

The condition of membership at the close of each of the past four years is shown in the following analysis:

	1947	*1948*	*1949*	*1950*	*1950 Growth*
Active Members	1,302	1,446	1,597	1,674	77
Associate Members	220	271	494	603	109
Student Members	68	102	245	285	40
Honorary Members (living)	3	3	3	4	1
Totals	1,593	1,822	2,339	2,566	227
Increase over prior year	214	229	517	227	

The data shown in the tabulation indicate that the greatest growth percentagewise as well as in numbers has occurred with the associate membership. The rate of increase in the student membership has decreased considerably from 140 percent in 1949 to 16 percent in 1950. This is perhaps due to the student sections having been established in prior years and to a general decrease in number of students attending college.

The decrease in the rate of increase in the number of active members from 10.4 percent to 4.8 percent is perhaps due to the fact that the membership committee has worked on an informal basis. No doubt a more active campaign would have resulted in a larger increase in members.

A study of the problems related to the maintenance of a steady growth in membership indicates that the committee should have solicited new members by forwarding application forms to non-members who registered at the many regional meetings. The personnel lists of the contracting geophysical companies and the oil company geophysical departments should be examined for prospective members. Another fertile source for members is through the use of our present members as salesmen.

KENNETH E. BURG, *Chairman*

EXHIBIT E. REPORT OF HONORS AND AWARDS COMMITTEE

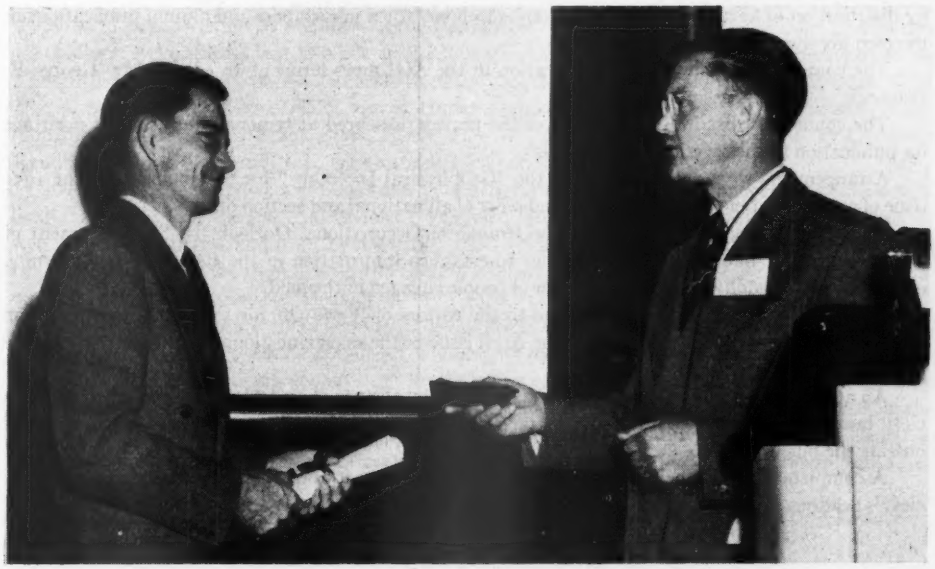
The Committee Members and the expiration of their terms are: Curtis H. Johnson (1951), Frank Goldstone (1952), Sidon Harris (1953), Norman Ricker (1954), and L. L. Nettleton, *Chairman*.

The several members of the committee suggested a total of fourteen papers as worthy of some consideration as the best of the year. Selection of a single one proved difficult because of the high quality of several. The final choice of the paper by Miller Quarles, Jr., on "Fault Interpretation in Southwest Texas" was based on its clear presentation and the practical utility of its material. The paper by George Woollard on "The Gravity Meter as a Geodetic Instrument" was considered well worthy of honorable mention.

No new honorary memberships were suggested by the committee for this year.

A contest among all members for the design of an official crest for the Society was announced in the October number of *Geophysics* and was repeated in the January number. First prize is a paid up life membership in the Society, including subscription to its *Journal*. Up to this time, the committee

AWARD FOR BEST PAPER OF 1950



Miller Quarles, Jr. (left) receives the Certificate and Plaque from President Wagoner. Presentation was made before the joint meeting of the American Association of Petroleum Geologists, Society of Economic Paleontologists and Mineralogists, and Society of Exploration Geophysicists at Hotel Jefferson, St. Louis, Missouri on April 24, 1951. The best paper award was presented Mr. Quarles for his publication of "Fault Interpretation in Southwest Texas," *Geophysics*, July, 1950.

has had only eight entries in this contest. These entries contain designs which would be quite suitable but the committee felt that the contest should be more representative of the membership. Therefore, it is the committee's recommendation that the contest be extended to close one month before the next annual meeting and that further publicity be given to the contest.

L. L. NETTLETON, *Chairman*

EXHIBIT F. REPORT OF THE STANDING COMMITTEE ON PUBLIC RELATIONS AND PUBLICITY

The membership of the Standing Committee on Public Relations and Publicity of the Society of Exploration Geophysicists is as follows: Paul L. Lyons, *Chairman*, Colin Campbell, Joseph D. Eisler, Robert B. Galeski, Norman J. Christie, W. C. Kimball, F. H. Kennedy and Fred G. Knight.

In fulfillment of its duties, the committee reports the following activities during the past year:

Fifteen national news releases were made. As in the past, these releases were written out completely in conventional newspaper style. The releases were sent to eighty-two addresses, using the new facilities at the headquarters in Tulsa. The list includes newspapers in the oil cities, oil journals and news services, news syndicates, officers of the society, and members of the publicity committee. The publicity chairmen of the local sections constitute this committee. Upon receipt of a news release it is their responsibility to contact the editors of local newspapers to assure publication if possible.

The committee with the assistance of the business manager distributed releases for the national convention in advance and secured publication of Mr. Wagoner's speech and Dr. Eckhardt's speech in the convention issue of the Oil and Gas Journal. St. Louis radio stations and a national news commentator were contacted for broadcasts of convention news items.

The committee reported honors bestowed upon members of the society and supplied interested local publications with news items and photographs.

The committee publicized the candidates nominated and elected to the society's national offices by distribution of news items and photographs to home town newspapers and alumni publications of the men involved.

The committee assisted in the publication in the AGI news letter of an editorial by George E. Wagoner.

The committee distributed abstracts of the papers presented at regional and national meetings for publication in the several trade journals.

Arrangements were made again with the "Geophysical Directory" for free inclusion in the 1951 issue of a statement of the society's aims and a list of all national and section officers.

The committee corresponded with the Branch of Occupational Outlook, U. S. Department of Labor, Bureau of Labor Statistics, in order to establish information in the Bureau files concerning opportunities in geophysics and the number of people engaged in the field.

The committee expressed appreciation to the editors of *World Oil* for seven feature articles on geophysical subjects which appeared in the April issue of the magazine along with an editorial on oil finding.

An appreciable savings in news costs was realized by the use of an addressing machine at the society headquarters. Formerly the mimeographing and distribution of news releases was performed outside the business office.

A complete file of all news releases accompanies this report and will be placed on file at the society's headquarters.

RECOMMENDATIONS

1. The business manager should be charged with initiating and writing up routine releases at the society headquarters. The committee would continue to initiate special releases and consider other aspects of public relations.

2. The committee has duly noted the proposed public relations program now advocated by the American Geological Institute and recommends its consideration by the council of the society.

In conclusion, the committee again emphasizes the value of sound publicity to the science of geo-

physics. The committee further notes a difference between publicity and public relations, and stresses the point that public relations may best be served by the individual actions of each member of the society.

PAUL L. LYONS, *Chairman*

EXHIBIT G. REPORT OF THE DISTINGUISHED LECTURES COMMITTEE

As distinguished lecturer for the year 1950–51, the committee secured Prof. Sydney Chapman, an outstanding authority on geomagnetism. Prof. Chapman is Research Associate at California Institute of Technology, on leave from Oxford University, where he is professor of mathematics and natural philosophy.

During the eight day period, March 26–April 2, Prof. Chapman delivered his lecture, entitled "Survey of the Present Problems of the Magnetism of the Earth," to members of the geophysical societies and their guests at Denver, Tulsa, Houston, Dallas, Fort Worth, and Shreveport; conferred with geophysicists in these cities; and visited geophysical laboratories in Denver, Tulsa, Houston, and Dallas.

The total cost of the tour was $539.98, which was prorated among the various societies in proportion to the membership of each, the prorated cost per member being $0.66.

JOSEPH A. SHARPE, *Chairman*

EXHIBIT H. REPORT OF THE STANDING COMMITTEE ON REVIEWS

The Reviews Committee appointed in 1949 by the Editor terminates its two-year term of service with this meeting. Its membership in addition to the chairman has been as follows: Arthur A. Brant, Francis F. Campbell, Kenneth L. Cook, C. G. Dahm, A. J. Hermont, J. Brackett Hersey and Nelson C. Steenland.

A report of the Committee's activities during its first year was made at the 1950 annual meeting. During its second year the Committee has been responsible for 54 reviews published in *Geophysics*. These were either written by members of the Committee or solicited by them from other members of the Society. Acknowledgment is made to the following persons, who in addition to members of the Committee, have kindly contributed reviews to the past four issues of *Geophysics:* W. T. Born, C. H. Dix, T. A. Elkins, H. H. Frost, R. A. Geyer, Hubert Guyod, Sigmund Hammer, M. T. Kozary, Henry Nogami, Jack W. Peters, Frank Press, H. Rainbow, W. M. Rust, Jr., Joseph Sharpe, D. C. Skeels, Rauol Vajk, Dart Wantland, J. E. White and W. J. Yost.

Of the 55 reviews, 15 were of books and 33 of articles while two were announcements of new publications. About half the material reviewed was from foreign sources. Publications in this category were in eight languages and from 14 countries. The Committee was particularly fortunate in having the services of reviewers from among the Society's membership who, collectively, could handle material in such a wide variety of languages.

Because most of the world's significant geophysical literature is from sources that are widely scattered and is in many diverse languages, the reviews pages of *Geophysics* have an important function in helping the practicing geophysicist keep abreast of developments in his field. The Chairman wishes to thank all who have generously contributed their time and efforts toward this objective: the Committee members and other reviewers, the Business Manager, who by sending us all exchange publications has provided the Committee with most of its review material, and the many publishers who have donated copies of new books for review.

MILTON B. DOBRIN, *Chairman*

RADIO FACILITIES COMMITTEE
1950–1951 REPORT

(A) *Organization*

National Committee

Chairman: R. D. Wyckoff, Gulf Research & Development Company, P. O. Drawer 2038, Pittsburgh 30, Pa.; Vice Chairman: W. M. Rust, Jr., Humble Oil & Refining Company, 257 Humble Building, Houston 1, Texas; Members: All Chairmen of Regional Subcommittees.

Regional Subcommittees

California—Chairman: Bart W. Sorge, United Geophysical Co., 595 E. Colorado St., Pasadena 1; Dean Walling, Western Geophysical Company, 1333 S. Hope Street, Los Angeles; H. R. Thornburgh, Shell Oil Company, 2310 Paloma Street, Pasadena 7; R. C. Dunlap, Jr., Geophysical Service, Inc., Fresno.

Dallas, Texas—Chairman: E. M. Shook, Magnolia Petroleum Company, Box 900, Dallas; F. A. Brock, Geophysical Service, Inc., 6000 Lemmon Avenue, Dallas; Frank Kennedy, Geotechnical Corporation, Box 7166, Dallas; W. R. Mitchell, National Geophysical Company, Tower Petroleum Bldg., Dallas; J. P. Woods, Atlantic Refining Company, 4500 Mockingbird Lane, Dallas.

Fort Worth, Texas—Chairman: V. Robert Kerr, Cummins, Pishney & Berger, Fort Worth; Robert E. Klabzuba, Texas Pacific Coal & Oil Company, Fort Worth; S. E. Van Steenbergh, Sinclair Prairie Oil Company, Fort Worth.

Houston, Texas—Chairman: W. M. Rust, Jr., Humble Oil & Refining Co., 257 Humble Bldg., Houston 1; L. M. Hubby, The Texas Company, Houston; S. Kaufman, Shell Oil Company, Inc., 3737 Bellaire Boulevard, Houston 5; H. E. Banta, Independent Exploration Company, Esperson Building, Houston; F. F. Reynolds, Seismic Explorations Company, Houston.

Tulsa, Oklahoma—Chairman: Daniel Silverman, Stanolind Oil & Gas Co., 5th & Boston Sts., Tulsa; E. M. McNatt, Carter Oil Company, P. O. Box 801, Tulsa; J. E. Hawkins, Seismic Service Corporation, P. O. Box 1590, Tulsa 1; J. A. Sharpe, C. H. Frost Gravimetric Surveys, Inc., Box 58, Tulsa; W. T. Born, Geophysical Research Corporation, Tulsa; A. J. Hintze, Phillips Petroleum Company, Phillips Building, Bartlesville, Okla.

Shreveport, Louisiana—Chairman: Richard Brewer, Atlantic Refining Company, Shreveport; J. E. Walker, Shell Oil Company, Inc., Box 789, Shreveport; Herbert A. Morriss; Glenn J. Baker, Wm. M. Barret, Inc., 909 Gliddens-Lane Building, Shreveport.

Special Representation

(1) American Petroleum Institute
API Central Committee on Radio Facilities
Subcommittee on Geophysical Use of Radio

(Membership from SEG Committee by organizational agreement)

R. D. Wyckoff, Chairman
W. M. Rust, Jr., Vice Chairman
Daniel Silverman

(2) *National Petroleum Radio Frequency Coordinating Association*

Comprises seven *Administrative Regions* in each of which exists a *Regional PRFC Association* with officers elected annually by membership.

National Executive Committee

(1) Acts for the National Association unless a national meeting is considered necessary.
(2) Membership—12—including:
7—Elected chairmen of each Regional Association.
5—Elected by above seven members—one each from the following divisions of the Petroleum Industry:
(1) Production
(2) *Geophysical* (nominally, Chairman of SEG Radio Committee)
(3) Oil and Products Pipe Lines
(4) Gas Pipe Lines
(5) Refining

National Association—Officers

Chairman
Vice Chairman } Elected from and by majority vote of the above Executive Committee.
Secretary-Treasurer

(This organizational setup was designed to facilitate conducting of annual business.)

The above organizational plan is presented to clarify the representation held by the geophysical industry through the multiorganization setup that was found necessary, in order that the petroleum industry might properly comply with the provisions of Section 11.57 of the FCC Rules and Regulations. It is to be noted that the geophysical industry is adequately represented throughout.

(*B*) *Minutes of 1950 Radio Facilities Committee Meeting*
Room 8, Third Floor, Stevens Hotel, Chicago, Illinois
April 24, 1950

In accordance with announcements at the General Sessions and Business Meeting of the Society, a meeting of the SEG Radio Facilities Committee and all interested parties was called to order at 5:00 P.M. by Chairman Wyckoff.

The following were present: Bart W. Sorge, United Geophysical Company, Pasadena, California; Homer Jensen, Aero Service Corporation, Philadelphia, Pennsylvania; B. Davis, Fairchild Aerial Surveys, Inc., Los Angeles, California; John Monkhouse, Rogers-Ray, Inc., and Robert H. Ray Co., Houston, Texas; J. O. Parr, Petty Laboratories, Inc., San Antonio, Texas; C. E. Buffum, Stanolind Oil & Gas Company, Tulsa, Oklahoma; E. M. Shook, Magnolia Petroleum Company, Dallas, Texas; L. C. Brieger, Atlantic Refining Company, Dallas, Texas; A. C. Winterhalter, Sun Oil Company, Beaumont, Texas; J. E. Hawkins, Seismic Service Corporation, Tulsa, Oklahoma; David Sheffet, Western Geophysical Company, Los Angeles, California; R. D. Wyckoff, Gulf Research & Development Company, Pittsburgh, Pa.

The Chairman briefly outlined the activities of the Committee in recent months and, in particular, the pending FCC Hearing on Docket 9233 Radiolocation Service, which was unexpectedly called but postponed in February, again April 17, and now stands indefinitely postponed awaiting opportunity for the FCC to fit it into their crowded schedule. It was explained that the Committee, through the API Central Radio Facilities Committee, stands prepared for this Hearing.

Attention was called to the agreement on the part of the geophysical services at the June 13, 1949, meeting, Kansas City, Missouri, of the National Petroleum Radio Frequency Coordinating Association, that: "subject to further advice from the SEG Radio Facilities Committee, geophysical applicants would have a final stage power input limitation of 100 watts except in the 1,600–1,700 kc band where the final stage power input would be limited to 25 watts."

Recently, several geophysical users have pointed out that, under special circumstances, higher powers have been in use and are necessary.

Chairman Wyckoff then advised that in informal conversations with the FCC engineers some time ago, he was assured that no objections would be raised to 100 watts maximum power on the 1,600 to 1,700 kc bands and that the use of such power, when circumstances demanded, would not prejudice our position in that band.

Mr. Shook then moved that: "The National Petroleum Radio Frequency Coordinating Association be instructed to approve geophysical license applications in the 1,600–1,700 kc geophysical channels with a maximum power input to the final stage of 100 watts, provided evidence for actual need for this maximum power accompanies the application."

This motion was seconded from the floor and discussion was requested.

In response to the suggestion that the motion include a requirement for suitable means for conveniently and positively reducing the power of the transmitter to 25 watts maximum input for ordinary use, it was pointed out by several members that reduction of power to minimum needs is already required by FCC regulations. Thus it was considered irrelevant to add such a provision in

our instructions to the NPRFCA. Accordingly, such an amendment was removed from further consideration.

A vote on the original motion was then taken, and it was carried unanimously.

Mr. Shook pointed out that the 100-watt limitation on *all* frequencies *above* the 1,600–1,700 kc band might not be clearly understood from the actions taken at the June 13, 1949, meeting of the NPRFCA, since the status of some of the higher frequencies was not clear at that time. The chairman agreed to advise the NPRFCA that the 100-watt limitation applied to these geophysical channels.

The meeting adjourned at 6:05 P.M.

(C) *Activities 1950/1951*

(1) *FCC Docket 9233—General Radiolocation Hearing*

This Hearing last scheduled for April, 1950, was postponed indefinitely. However, a suitable joint statement was prepared for presentation through the API Committee. Subsequently, this statement was presented informally and reviewed by the Armed Services and FCC. Apparently, as a result, the situation has been clarified to the point that the Commission has cancelled the issues of the original Hearing and substituted the following—quoted in content only:

(1) Whether frequencies in the 1,850–1,800 kc band should be allocated at this time for a Radiolocation Service (in the Gulf of Mexico only) in the light of the possibility of interference to and from the Disaster Communications Service (allocated in this band by some international agreements).

(2) The nature and extent of any plans for the development and use of a Radiolocation Service on these frequencies in the near future.

(3) Whether in the event such an allocation is authorized, the proposed new rules for a developmental Radiolocation Service should be adopted.

The proposed new rules referred to in (3) are set forth in an attachment to the notice. They include the following proposed frequencies:

(a) 1,750–1,800 kc (for Gulf of Mexico only and other restrictions).

(b) 2,450–2,500 mc (on noninterfering basis with fixed and mobile service).

(c)

2,900–3,246 mc	5,460–5,650 mc
3,266–3,300 mc	9,000–9,300 mc
5,250–5,440 mc	9,320–9,500 mc

Written comments relative to the proposed rules are to be filed with the Commission by interested parties by May 25, 1951, and a Hearing before a member of the Commission regarding the issues set forth is ordered on June 4, 1951, in Washington, D. C. Notice of intention to participate must be filed by May 25.

The above Notice of Hearing and Notice of Proposed Rule Making is 62304, FCC 51–323, released April 16, 1951.

Since the notice has just been received, plans are not yet formulated, but the matter will be handled through the API Committee and Special Representative, J. E. Keller, Munsey Building, Washington 4, D. C. Interested parties, if independently notifying the FCC of intent to participate, should send copies of such notice or comments to Mr. Keller in order to facilitate proper coordination.

(2) In accordance with the actions of the April 24, 1950, SEG Committee meeting and with the assistance of Mr. J. E. Keller, certain minor details retarding licensing procedure in the geophysical group of the Petroleum Service have been cleared with the NPRFCA and the FCC as follows:

(a) In the 1,600–1,700 kc channels, 100 watts maximum input will be allowed on *special* showing of need instead of the usual 10-watt limitation within this band.

This 100-watt maximum replaces the 25-watt maximum agreed upon for the 1,600–1,700 kc band at the NPRFCA, Kansas City meeting, June 13, 1949.

(b) Geophysical operators using the petroleum service frequencies agreed upon by the NPRFCA need submit their license applications for approval only to the Regional Chairman whose

jurisdiction covers the home office of the operator. The FCC will recognize such approval as applying to the entire U. S. except for a band—"Line 'A' "—some 75 miles wide adjoining the Canadian border and over its entire length.

Operation within the above boundary territory on frequencies above 30 megacycles will require special approval and a specific frequency assignment by the FCC (See Figure 1).

(3) A map was prepared showing the geographical location of the previously-mentioned "Line 'A' " boundary and a listing of specific frequency limitations within this zone as specified by the FCC. The seven jurisdictional regions of the NPRFCA are also shown.

Four hundred prints of this map were furnished to Mr. Keller for distribution and including a supply for the FCC at their request.

(D) *Future Activity*

There appear to be no new problems other than the pending Radiolocation Hearing requiring the attention of the Committee in the immediate future. Regardless of this, the committee must remain organized as a standing committee as long as the present API and NPRFCA organizations are required. In this manner the geophysical industry can be canvassed adequately and without delay on any question that may arise.

R. D. WYCKOFF, *Chairman*

PAPERS PRESENTED OR READ BY TITLE AT THE TECHNICAL SESSIONS OF THE TWENTY-FIRST ANNUAL MEETING HOTEL JEFFERSON, ST. LOUIS, MISSOURI APRIL 23–25, 1951

A Geophysical Study of the Owasso Dome, Tulsa County, Oklahoma.

V. L. JONES, Consulting Geophysicist, Tulsa, Oklahoma.

The Owasso dome is situated in an old oil- and gas-producing area, and is located 2 miles west of the town of Owasso and about 12 miles north and east of the city of Tulsa. The presence of granite immediately underneath the Chattanooga shale on this structure is indicated by well data. This suggests the strong possibility of the existence of a magnetic and also a gravity anomaly. Magnetic intensity maps are presented which show the character of the total, vertical, and horizontal fields associated with this feature. A gravity map is likewise presented together with a geologic structure map contoured on the Fort Scott limestone, and a surface topographic map contoured from gravity elevation data. These various maps show an excellent correlation of gravity and magnetic data. They also show a striking correlation with structure.

Reflection Shooting on the Edwards Plateau.

THOS. C. POULTER AND L. V. LOMBARDI, Stanford Research Institute, Stanford, California.

An analysis is made of the energies which appear on seismic records obtained on the Edwards Plateau, and such factors as multiple reflections, high-frequency effects from superposition, and the jointed or "block" condition of the surface are evaluated.

As many as sixty multiple reflections are identified on a single record and means for almost completely eliminating them are described. The effect of superposition on the high frequency appearance of the records is illustrated. The use of multiple phones and mixing in overcoming some of the effects of the jointed or "block" condition of the surface is described, and the use of a pattern of small charges combined with the directivity thus obtained for improving the signal to noise ratio are described.

Some of the problems described and the general conclusions are based on an analysis of the records from more than 300 miles of survey in Crockett, Sutton, Pecos, and Schleicher counties, Texas.

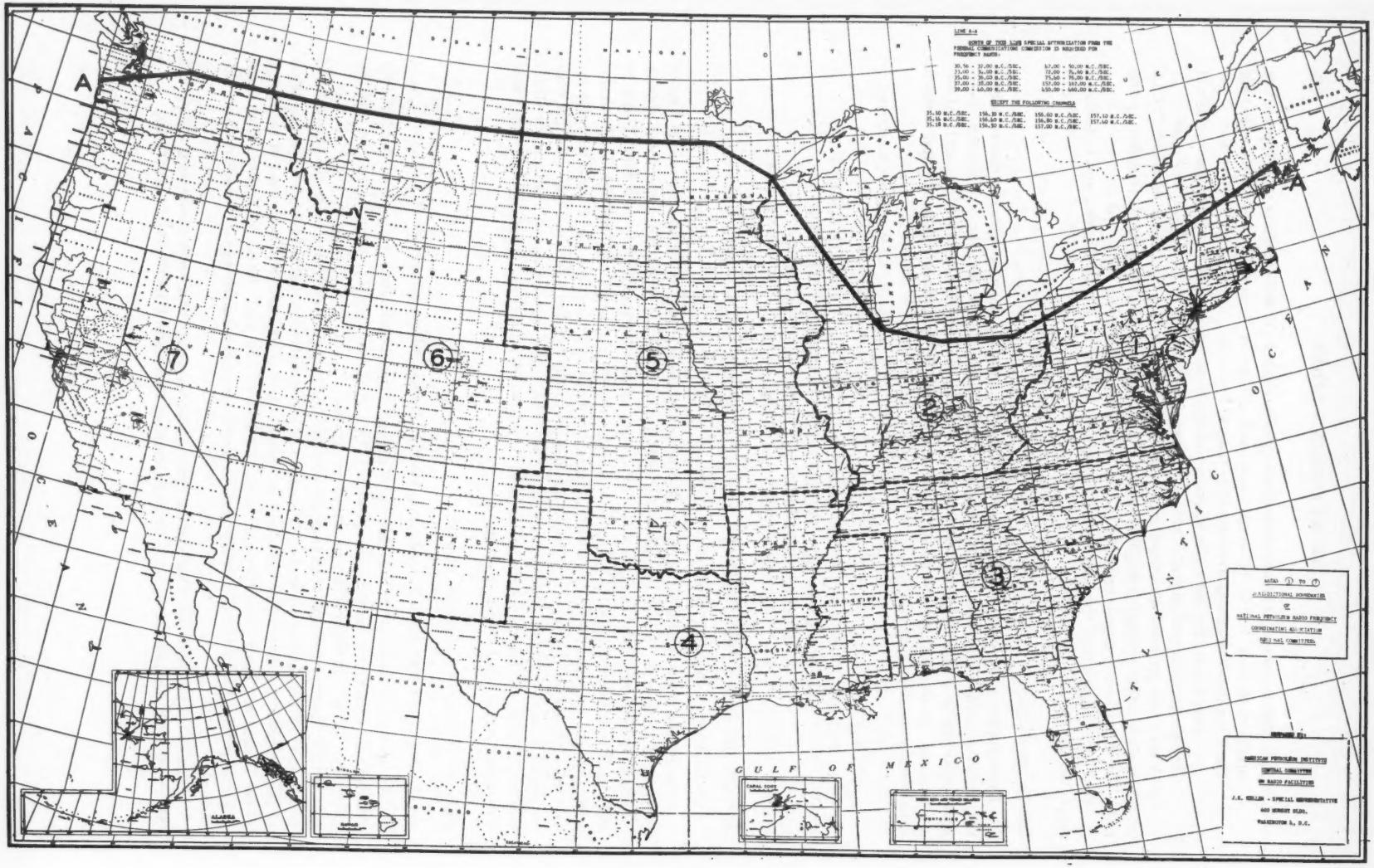


FIG. 1. Boundary Territory.

The A.G.I. in the National Emergency.

DAVID M. DELO, Executive Director, American Geological Institute, Washington, D. C.

Latest developments concerning national plans for education and utilization of scientific manpower during the continuing emergency are described and analyzed. The program of the American Geological Institute in this area is explained in terms of national integrated activities which can be of specific service to the geological professions. These include co-operation with other scientific organizations and governmental agencies in formulating recommendations and plans, establishing a roster of all geologists and geophysicists in Service, formulation and distribution of recommendations for the best use of geologists and geophysicists by the Military Services, and supply and demand studies. The role of public information activities in calling attention to the essential nature of the civilian work of geologists and geophysicists is also considered as a facet of this program.

*Variation of Elastic Velocities in Rocks with Pressure and Temperature.**

DARRELL S. HUGHES, University of Texas, Austin, Texas.

A laboratory method of measuring dilational and rotational velocities in rocks subject to hydrostatic pressure and high temperature has been developed. Representative samples of igneous, sedimentary, and metamorphic rocks have been studied. Most samples have been studied from room conditions to 15,000 psi and 200°C.; several samples have been studied to 75,000 psi and 300°C. The effect of included water has been studied for a few samples.

The dilational velocities are measured with an accuracy of about 0.2 per cent and the rotational velocity with an accuracy of about 0.5 per cent.

The Application of the Reflection Seismograph to the Search for Stratigraphic Traps.

W. E. PUGH AND H. M. THRALLS, Seismograph Service Corporation, Tulsa, Oklahoma.

Reflection seismograph surveys by the continuous-profile method furnish opportunities for compilation of mass data. When these data are obtained and compared with detailed geologic information some time differentials are observed which can not be ascribed to changes in depth of reflecting horizons. Analyses of these types of time differentials suggest an interpretative approach to outlining changes in stratigraphy. An example of the possibilities of such an analysis is cited—the interpretative technique applied to the South Ceres sand-lens pool in Noble County, Oklahoma.

A revision in the over-all interpretative approach is needed if many stratigraphic-type oil traps are to be found with the seismograph. Important test wells should be seismo-logged as well as electro-logged. Provisions should be made for more exact determination of interval velocities to provide for a study of interval velocity gradients as well as average velocity gradients.

Seismic Record Sections.

H. R. PRESCOTT, Continental Oil Company, Houston, Texas.

A method is described whereby seismic records may be secured which have sufficient dimensional stability that a composite reprint of several records, from a continuous profile, when placed in proper sequence, yields a cross section of seismic arrivals. A method is described for entering corrected time scales on the seismic record section itself. Double recording is provided, with traces in transposed positions but alike in phase relation, which makes possible the construction of closed traverse sections. A few examples of the record section are shown and some uses suggested.

Geophysical Activity in 1950.

E. A. ECKHARDT, Gulf Research and Development Company, Pittsburgh, Pennsylvania.

This is the report for 1950 of the S.E.G. Standing Committee on Review of Geophysical Activity.

* This work was supported by the Office of Naval Research under Contract N6onr-266, Task Order VIII, and by research grants from The Shell Oil Company and the Humble Oil and Refining Company.

FIG. 1. Boundary Territory.

The report covers the volume of geophysical activity, its geographic distribution and discernible trends. The lull in geophysical activity which caused considerable concern a year ago proved to be short-lived and the volume attained a new all-time high in 1950.

Seismic Velocity as a Function of Depth and Geologic Time.

L. Y. FAUST, Amerada Petroleum Corporation, Tulsa, Oklahoma.

Velocity of longitudinal seismic waves as a function of depth of over-burden and of geologic age was studied in more than five hundred velocity surveys. Except for a brief reference to limestone velocities the paper is concerned with velocities in sections of sand and shale. Averaged interval velocities of shale and sand sections are presented graphically arranged by depth and age. The effect of lithologic variations is discussed.

A formulation of the quantitative relationship between the variables is attempted in the latter part of the paper. It is concluded that velocity in feet per second for an average shale and sand section at a depth of Z feet and of age T years is given by: $V = 125.3\ (TZ)^{1/6}$.

Geophysical Methods Adapted to Highway Construction Problems.

R. WOODWARD MOORE, Head of Geophysical Explorations Unit, U. S. Bureau of Public Roads, Washington 25, D. C.

Of the several geophysical methods used in exploration for oil and useful ore bodies, the earth-resistivity and seismic-refraction tests have been found to be the most adaptable to the shallow tests generally required in highway construction work. Of these, the earth resistivity test is the faster and has a wider range of application to highway problems than does the seismic test. Use of both methods of tests in subsurface explorations for engineering structures is expanding.

The paper cites a growing need for a more thorough subsurface investigation of all engineering structure sites and gives examples of field data obtained by the Bureau of Public Roads when making preliminary geophysical surveys of proposed highway locations or structure sites.

The economic aspects and the advantages and limitations of the two methods of test are discussed with particular reference to their application to highway engineering problems.

Safety and Geophysical Exploration.

BART W. SORGE, United Geophysical Company, San Gabriel, California.

The idea that geophysical operations are dangerous can be proved false. The co-ordinated safety program backed by all parts of an organization will produce results. Advantages may be gained from co-operation in safety matters among operators of geophysical crews.

Seismic Reflection Quality Map of the United States.

To be discussed by PAUL L. LYONS, Carter Oil Company, Tulsa, Oklahoma.

A reflection-quality map of the United States has been prepared by a subcommittee of the Program and Arrangements Committee. The map designates as good, fair, poor, or NG all sedimentary areas where sufficient knowledge from conventional seismic operations is available. The map may be used in the planning of geophysical operations. Reflection quality is a function of many geological factors.

Geophysical Exploration of Southwest Hungary.

RAOUL VAJK, Standard Oil Company of New Jersey, New York City.

Geophysical exploration of an 8 million-acre oil concession covering southwest Hungary is discussed in this paper.

During the 10 years of exploration (1933–1943), about 20,000 torsion-balance, 12,000 gravity-meter, and 15,000 magnetometer stations were made and reflection seismograms were recorded at

about 2,500 shot points. As a result of this exploration, four oil fields and a gas field were discovered and a number of geological structures and major faults were located and outlined.

Gravity, magnetic, and seismic maps showing most of the geophysical data are submitted. Interpretations of the geophysical results, geological data of subsequent drilling and a schematic tectonic map of southwest Hungary based on the geophysical surveys are also given.

The Effect of Random Errors in Gravity Data on Second Derivative Values.

THOMAS A. ELKINS, Gulf Research and Development Company, Pittsburgh, Pennsylvania.

Two random-error grids were prepared by using a set of 111 balls marked according to the Gaussian normal-error law. For these grids, considered as grids of errors in gravity data, the second derivative values were computed and contoured. The resulting maps show strikingly the dangers in uncritical interpretations of second-derivative maps based on insufficiently accurate data.

Statistical checks were applied both to the random-error grids and to the computed second-derivative values. The check on the latter necessitated the development of a theory of the correlation between second-derivative values.

Delineation of Sedimentary Basins by Means of Magnetics.

JAMES AFFLECK, Gulf Research and Development Company, Pittsburgh, Pennsylvania.

The calculation from various types of magnetic anomalies of depths to magnetic basement yields useful information for the delineation of sedimentary basins. A number of typical anomalies are shown on slides, and the results of depth calculations are discussed, together with the inherent limitations of the method.

Magnetic Well Logging.

R. A. BRODING, C. W. ZIMMERMAN, E. S. WILHELM, A. A. STRIPLING, Magnolia Petroleum Company, Field Research Laboratories, Dallas, Texas.

The need for control data in interpretation of surface magnetometer surveys has led to the development of borehole instruments for measuring magnetic susceptibility and total magnetic field *in situ*. The susceptibility instrument is an alternating current induction device and by separation of the quadrature components, simultaneous recording of the magnetic susceptibility and the electrical conductivity is possible. The susceptibility log has many features that depart from ordinary electric logs. The instrument has a sensitivity of the order of 1×10^{-6} cgs units and sufficient contrast has been found in the sediments to yield a log of considerable lithologic character. This magnetic character suggests the use of the susceptibility tool in the field of special well logging, particularly for geologic correlation, and for tracer studies. The general assumption that the magnetic susceptibility of the sediments is sufficiently low compared with basic igneous rocks and that sedimentary rocks have little effect on surface magnetometer measurements has been verified. Since the magnetic susceptibility and electrical conductivity logs are made with an induction instrument, an electrolyte is not required in the hole and the logs are independent of the drilling fluid, except that the conductivity log is influenced by highly conductive muds.

The total field log is made with a three element self-orientating saturable core magnetometer that has been developed for borehole use. This log has not been used extensively. In addition to reflecting changes in polarization of the formations, it is influenced by formation susceptibility. Logs have been made of the total field going into and through igneous plugs.

The paper presents examples of these logs along with a brief description of the instruments developed to produce them.

Regional Gravity Survey in Northeastern Oklahoma and Southeastern Kansas.

KENNETH L. COOK, U. S. Geological Survey, Salt Lake City, Utah.

In 1948 the Geophysics Branch of the U. S. Geological Survey, in co-operation with the U. S. Coast

and Geodetic Survey, made a regional gravity survey in northeastern Oklahoma and southeastern Kansas. In Oklahoma about 370 gravity stations, located at points forming approximately rectangular patterns with 5- to 10-mile spacings between individual stations, were taken in parts of 30 counties. In Kansas about 180 stations located, similarly with about 10-mile spacings between individual stations, were taken in parts of 24 counties. The gravity data, which were obtained with a Frost gravimeter, were reduced by conventional methods to give simple Bouguer gravity values of the surveyed area. A Bouguer gravity anomaly map, contoured at intervals of 5 milligals, is presented and discussed. In most of the surveyed area the pre-Cambrian basement complex lies within a few thousand feet of the surface of the earth. The observed Bouguer gravity anomalies are apparently caused largely by variations in either the composition of the pre-Cambrian basement complex or the present topography of the pre-Cambrian surface, or a combination of these two factors.

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Regionals, Residuals, and Structures.

L. L. NETTLETON, Gravity Meter Exploration Company, Houston, Texas.

Since the earliest applications of gravity and magnetic methods, interpreters have recognized the problem of separating local from regional effects. Residual anomalies have been determined by simple inspection, by smoothing contours, by profiles and by a variety of numerical schemes including the calculation of higher derivatives. The possibilities and limitations of the various methods are illustrated by examples. It is pointed out that the inherent ambiguity of the interpretation of potential fields precludes the general and automatic application of any single scheme of isolation of anomalies. The selection of significant anomalies is not an exact science but is largely an art, dependent on experience and on judgment which can be greatly aided by geological control.

The World-Wide Gravity Program of the Mapping and Charting Research Laboratory of the Ohio State University.

W. HEISKANEN, Director, Finnish Geodetic Institute; Director, Isostatic Institute of I.A.G.; Consultant, Mapping and Charting Research; Laboratory of the Ohio State University.

The gravity anomalies are an important tool in the hands of the exploration geophysicists. But they also have a very great geodetical significance. They enable us to determine the shape of the earth—the only method which at least now can do it. The gravity anomaly maps of the earth, which present in broad lines the gravity field of the world, enable us to compute the undulations of the geoid. We can also by means of these anomaly maps compute the absolute deflections of the vertical at any point in the vicinity of which a local gravity survey exists—at least about 100 stations inside the circle of 200 kilometers radius. By means of these absolute deflections of the vertical we can convert the astronomical to geodetic positions.

We have in the Mapping and Charting Research Laboratory in Columbus planned a world-wide gravity program by the aid of which we can obtain the following aims:

a. To determine a general World Geodetic System and to convert the geodetic systems (North American, European, Russian, and so on) to this system.

b. To be able to compute, on the World Geodetic System, the geographical co-ordinates of any important point in the world where astronomical observations exist or which is plotted on a local map with a reliable grid.

c. To be able to compute the distances and directions between any required points in the world.

d. To control the maps on scale 1:100,000 and on smaller scales.

e. To study the size and shape of the earth's ellipsoid and geoid.

About 3,000 new gravity stations evenly distributed and many local gravity surveys and, of course, an enormous amount of analyzing work are needed. Many leading scientists and some universities have already promised a close co-operation. We hope to get much valuable help also from the side of the prospecting geophysicists.

Analytical Iso-Horizon dZ/dT Relations for the Solution of Seismic Reflection Data.

P. E. NARVARTE, Consulting Geophysicist, San Antonio, Texas.

From a given linear velocity distribution increasing with depth, analytical iso-horizon dZ/dT relations applicable to the solution of reflection data are presented which take into account the factors of load, lithology, and geologic age, and the structural attitude of the bedding planes. The analytical relations confirm an empirical relation previously introduced and offer the same distinct advantages and ease of application.

Some Experiments with Elastic Waves in the Ground.

J. E. WHITE, Magnolia Petroleum Company; Field Research Laboratories, Dallas, Texas.

Procedures are described for observing disturbances at short distances from explosions and impacts in shallow boreholes. Under many conditions, transients of pressure or particle velocity measured at various distances yield compressional and shear speeds for the formation. Fourier analyses of such transients can be made to give attenuation as a function of frequency. The velocity of compressional waves in the borehole fluid depends on formation rigidity.

Plots of compressional, shear, and borehole velocities as a function of depth are shown for several locations. It is concluded that Austin chalk and Eagle Ford shale are approximately uniform when averaged over distances comparable with seismic wave lengths, but both formations are significantly anisotropic. For horizontally-travelling compressional waves, attenuation is shown to be directly proportional to frequency for both formations, with quite different constants of proportionality. Both compressional and shear velocities for a loose-sand area are shown to increase smoothly with depth except for an abrupt increase in compressional velocity at the ground-water level.

The Generation and Propagation of Strain Waves in Rock.

LEONARD OBERT, WILBUR I. DUVALL, THOMAS C. ATCHISON, U. S. Bureau of Mines, Washington, D. C.

The "near-shot" generation and propagation of strain waves has been studied for shot sizes from 1 to 100 pounds. First, strain gages and recording equipment were developed which could be employed in solid media (rock). Field studies were made in a number of rock types, and an empirical relationship between the shot size, distance, and strain developed. This relationship contains two constants which can be related to the rock type, explosive, and other experimental parameters, and these parameters can be compared through the evaluation of these constants. The strain pulse resulting from the application of a step-function pressure pulse to a spherical cavity in a solid medium has been calculated and compared with recorded strain pulses. Also, the resonance of a spherical cavity in a solid medium driven by a sinusoidal source has been calculated and the results compared with field data.

Ground Roll Coupling to Atmospheric Compressional waves.

FRANK PRESS AND MAURICE EWING, Columbia University, New York City.

A theoretical treatment of ground roll originating from air shots and hole shots is given. In most regions Rayleigh wave velocities vary with period due to layering, being less than the speed of sound in air for short periods and exceeding this value for longer periods. It is shown that coupling of ground roll to compressional waves in the atmosphere exists for both air shots and hole shots in these regions. Experimental data obtained in the field are in excellent agreement with the theoretical results; namely, that the effective coupling exists for surface waves whose phase velocity is equal to the speed of sound in air.

It is also shown that body wave and surface wave character is almost independent of charge elevation in the range from 0 (on the ground) to 30 feet.

In a reciprocal manner ground roll from hole shots was recorded with air microphones as predicted by the theory.

Frequency Analysis of Seismic Waves.

J. J. JAKOSKY AND JOHN J. JAKOSKY, JR., International Geophysics Company, Los Angeles, California.

Four years laboratory and field work has been conducted in co-operation with a major oil company to determine the factors governing transmission of seismic wave energy through the earth. This paper describes phases of the work pertaining to frequency analysis of seismic waves and its application to seismology.

A discussion of the mechanism of seismic pulse generation is followed by discussion of factors governing changes in the spectral distribution of energy due to absorption, adsorption and scattering as the wave travels through the earth, the effects of low frequency cut-off, and variations in Δt by wave interference.

Examples are given from field work to illustrate changes in wage components under certain geologic conditions. The effects of air waves, surface waves, multiple reflections, and changes in spectral energy from shallow to deep reflections are shown after separating the various components by frequency analysis.

Illustrations and diagrams describe the equipment developed for this work. This instrumentation promises to be a powerful tool for seismic and geological research. By its use detailed studies may be made economically, with proper control of the parameters to be measured.

Seismic Wave Guide Phenomena.

K. E. BURG AND E. J. STULKEN, Geophysical Service, Inc., Dallas, Texas, FRANK PRESS AND MAURICE EWING, Columbia University, New York City.

On one particular prospect in shallow water, resonance, apparent standing waves, and other repetitive patterns appeared on short spread seismograms in such prevalence as to jeopardize identification of normal reflections. An explanation of these disturbances is developed.

It is demonstrated that under favorable conditions, less restrictive than thought necessary heretofore, a layer of water comprises an effective wave guide for seismic energy propagation. Reinforcement fronts formed by multiple reflection of sound in water can develop into a new set of waves completely over-shadowing all normal seismic arrivals. With but minor modifications conventional wave-guide theory applies.

Examples from the prospect are presented to illustrate various reinforcement patterns. Observed frequency characteristics, group velocity, and phase velocity magnitudes, as well as relative amplitudes, are investigated for particular modes of propagation. Possible extension of the treatment to include a wider range of seismic phenomena is indicated.

An Electromechanical Transducer for the Transient Testing of Seismographs.

PIERRE M. HONNELL, St. Louis University, St. Louis, Missouri.

The transient response of seismographs is probably the more important instrumental characteristic of these devices and may be computed analytically subject to some simplifications. Recourse to laboratory tests would be a useful procedure for determining this type of response. Many early devices designed to test seismographs dynamically were rather crude affairs and aptly named "shaking tables." However, the prior art discloses with apparently but a single exception no shaking table truly capable of reproducing transient motions other than the natural oscillations of the device itself.

The purpose of this paper is to describe the theory, the design, and the construction of an electromechanical transducer system which reproduces vertical mechanical motions in the image of arbitrarily specified waveforms for the transient testing of seismographs.

Routine Delta Tee Analysis for Field Crew Use.

CARL H. SAVIT, Western Geophysical Company, Los Angeles, California.

The process of obtaining accurate average velocities from moveout data is reduced to a routine

field operation requiring minimum computation. A comparison is made of velocity data so obtained with well-velocity data from a subsequent well. The accuracy of the method permits extensive applications, a few of which are discussed.

Seismic Profile Across the Hudson River Near Nyack, New York.

J. LAMAR WORZEL, Columbia University, New York.

A refraction-seismic section transverse to the Hudson River was made from Nyack to Tarrytown, New York. A basement horizon (velocity about 16,500 feet/second) identified with the Yonkers gneiss at the outcrop on the east shore was found to dip westward about 5°. A consolidated sediment horizon (velocity about 10,000 feet/second) identified with the Triassic in a borehole overlies the basement and pinches out against the basement near the east shore. The surface of this layer is nearly horizontal except for a section near the west shore where a V-shaped depression, probably a former channel, is incised into the layer to a depth of about 700 feet. An unconsolidated sedimentary layer (velocity about 5,600 feet/second) whose surface has only about 100 feet of relief, overlies the consolidated layer. An organic silt layer (velocity about 3,000 feet/second) forms the river floor and overlies the unconsolidated layer. Six sections transverse to the main profile are also described.

How Seismograph Interpretation is Related to Changes in Sedimentary Section in West Texas and New Mexico.

JOHN W. DALY, General Geophysical Company, Midland, Texas.
C. N. PAGE, Honolulu Oil Corporation, Midland, Texas.

The different rock types have characteristic seismic velocities. Within a given time-stratigraphic unit this may vary by as much as 300 percent. Portions of regional velocity maps which demonstrate this fact are shown. The effects of these sharp velocity contrasts on seismic interpretation are assessed.

Read by Title

The Anomaly Field of Structures of Simple Geometric Cross Section.

W. B. AGOCS, University of Tulsa, Tulsa, Oklahoma.

The magnetic- and gravity-anomaly fields have been determined for structures of simple cross section. The horizontal, vertical, and total magnetic anomalies, and the vertical gravity anomalies of these structures have been calculated so that they may be compared. These calculated anomalies may be used as comparison standards to observed anomalies. The second derivatives of the gravity and magnetic anomalies have been determined so that these theoretical determinations may be compared with those calculated from the observed field data. The computed curves may be used for the qualitative or quantitative evaluation of observed anomalies.

Least Squares Residual Anomaly Determination.

W. B. AGOCS, University of Tulsa, Tulsa, Oklahoma.

The residual anomaly is defined as the deviation from the mean anomaly surface, or the regional surface. The regional surface which best fits the observed anomaly data may be determined by least squares. For the case of the simple plane, the equation of the regional would be $Z=Ax+By+C$, and the residual anomaly would be $R=G-Z=G-(Ax+By+C)$, where G is the observed value at the station whose coordinates are x, y. The constants for the equation of the regional may be determined by using the normalizing equations

$$\sum \frac{R\partial R}{\partial A}=0;\ \sum \frac{R\partial R}{\partial B}=0;\ \sum \frac{R\partial R}{\partial C}=0.$$

It is shown that for a symmetrical distribution of observational points about a center, the regional value at the center would be equal to $\sum_{n=1}^{n} G_n/n$ and this value subtracted from the central point is the residual. Given the co-ordinates, and the observed values, the regional may be determined, and the residual for the area calculated rapidly. An example is given of the procedure.

POLICY FOR REGIONAL MEETINGS*

There has been some misunderstanding about the policy of the S.E.G. with regard to regional meetings. Therefore at the Fort Worth meeting on November 30, 1950, the executive committee instructed the president to appoint a committee to clarify the relationship between the local sections and the business office of the S.E.G. in regard to regional meetings. Mr. Wagoner appointed Francis F. Campbell as chairman of the committee and Andrew Gilmour and Colin C. Campbell as members.

In the past the regional meetings in the mid-continent area have been planned and administered by officers and committees of local sections, and the business manager of the S.E.G. has co-operated with them in making arrangements for technical sessions, in budgeting expenses, and in securing advertising for the programs. In the past only the travel expenses of the business manager have been paid. The committee highly commends the initiative of the local sections in planning regional meetings and assumes that the local sections will continue to display this initiative. The committee believes the S.E.G. should continue to encourage regional meetings through the co-operation of the business manager with officers and committees of local sections. However, the committee recommends that in the future 5 percent of the income from advertising in the program should be charged as a fee to compensate the S.E.G. business office for the expense of soliciting advertisers, preparing copy, and collecting accounts. It should be understood that the local sections are free to engage some one else to perform these services, and that if such an arrangement is made the business manager of the S.E.G. will still co-operate willingly in every other way.

ANNOUNCEMENTS

EASTERN REGIONAL MEETING

October 25, 1951

Plans are being made for holding an Eastern Regional Meeting of the S.E.G. at the Mellon Institute on Thursday, October 25, 1951. Arrangements for housing out-of-town visitors in the Webster Hall and Schenley Hotels are in progress. Plans call for a tour of the Gulf Research and Development Company laboratories on Friday, October 26. The possibilities of having geophysical exhibits in the Mellon Institute lobby are also under consideration. Several tentative commitments for new papers have been obtained with the intention of rounding out a full one-day program of good technical papers. R. B. Ross, Chairman of the Eastern Regional Program Committee, is in charge of arrangements. The other members of his committee assisting him are Frank Press and Bruno Winkler. L. F. Melchior is chairman of the Local Arrangements Committee. Detailed announcements will be mailed to members of the society well in advance of the meeting.

ANNUAL MIDWESTERN REGIONAL MEETING

November 19 and 20, 1951

The Baker Hotel, Dallas, Texas, will be the scene of the annual joint meeting of 1951, sponsored by the Dallas Geophysical Society, Fort Worth Geophysical Society, Permian Basin Geophysical Society, Ark-La-Tex Geophysical Society and Geophysical Society of Tulsa. The Tulsa section will be in charge of general arrangements through a committee composed of E. M. McNatt, Jay P. Garner, K. M. Lawrence, W. H. Courtier, Frank Searcy and Karl Dyk, Chairman. Most of the papers presented during the two-day meeting will concern geophysical problems encountered in the midwestern oil producing region of the United States, and will include a featured address by an outstanding exploration scientist. More than one thousand are expected to attend. Detailed announcement will be mailed to members of the society well in advance of the meeting, along with hotel reservations forms. Those who await receipt of the official announcement will be assured of obtaining better accommodations, because the hotels have reserved space for delegates who apply on the official form.

* Approved by the Council, April 24, 1951.

AMERICAN GEOLOGICAL INSTITUTE

The American Geological Institute issues a monthly NEWS LETTER which records current activities of the Institute or gives specific information of interest to geophysicists and geologists in general. The following items have been selected from recent issues of the NEWS LETTER as of interest to members of the Society of Exploration Geophysicists.

"Geology and Geophysics Retained on Critical Employment List:

Early in the Korean war (see Supplement August NEWS LETTER) a list of critical occupations was issued by the Department of Commerce based on statistics concerning supply and demand in various fields compiled by the Bureau of Labor Statistics during the first 60 days. There has been some discussion concerning the removal of Geology and Geophysics from this list. We are glad to report that discussion with representatives of the Bureau of Labor Statistics now indicates that Geology and Geophysics will be retained on the critical list."

"National Scientific Register Report:

Approximately 200 completed enrollment forms per day are being received at A.G.I. headquarters and processed for transmittal to the Bureau of Labor Statistics. A special unit of the Bureau will prepare IBM punch cards for each form. These should be available for analysis before January, 1952. It is interesting to note that although only 11,000 non-duplicating members were counted for the nine societies, almost 20,000 questionnaires and envelopes have been transmitted in response to requests from district Register committees. It is hoped that each geologist and geophysicist will send his form in promptly so that we can close the books on this project at the earliest practicable date. The Institute is very appreciative of the fine cooperation received from national and local societies and individuals in connection with the project."

"Office of Defense Mobilization, Science Advisory Committee:

President Truman has just appointed a Science Committee to advise Mr. Charles E. Wilson, Director of the Office of Defense Mobilization. It is interesting to note that five members of the committee are physicists, two are chemists, one a biologist, one a physician and two were trained in scientific and engineering administration. No representative of the earth sciences was appointed to the committee. Dr. O. E. Buckley is chairman of the committee. Other members are:

Detlev W. Bronk
William Webster
Alan Waterman
Hugh Dryden
James B. Conant
Lee Dubridge
James R. Killian
Robert F. Loeb
J. Robert Oppenheimer
Charles A. Thomas"

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The Institute has recently published a booklet on OUTSTANDING AERIAL PHOTOGRAPHS IN NORTH AMERICA. This is not a collection of pictures but rather is a very complete list of pictures which are particularly illustrative of certain geological or physiographic features. Detailed references are given on designations and sources to facilitate ordering pictures, most of which are from various government bureaus from which prints may be obtained at nominal cost. The booklet of 87 mimeographed pages is obtainable from the Institute, 2101 Constitution Avenue, Washington 25, D. C., for $1.00.

* * * * * *

"Guide to Geologic Literature:

This, the first book of its sort in the earth science field, is designed to help the geology student or the professional geologist find what he wants with a minimum of time and trouble. Pearl discusses the various sorts of geological literature—including bibliographies, abstracts, periodicals, bulletins, books, theses, and maps—describes their sources, organization, and uses, and explains how information can be located in libraries. The book contains a vast amount of data, much of which will be new,

doubtless, to many geologists and should become a standard work. Richard P. Pearl, GUIDE TO GEOLOGIC LITERATURE, New York, McGraw-Hill, 1951. 239 pages. Price $3.75. (Mark W. Pangborn)."

"Kansas Society Issues Cross Sections:

The Kansas Geological Society has announced the issuance of several electric log cross sections which are for sale by the Society. These include a section across Kansas along the Sixth Principal Meridian; one along the southern Kansas border; and a revision of a previously issued cross section from Western Missouri to the Colorado line. Two other cross sections involving the central states include a north-south section from Lake Superior to the Mexican Border and one from Granite Ridge in southeastern Nebraska to the Salem oil field in Illinois."

'Oil & Gas Technical Library Being Established:

Plans have been completed by the Ark-La-Tex Geophysical Society, the Shreveport Geological Society and the East Texas Chapter of the A.I.M.E. to establish a petroleum exploration library as part of the Shreve Memorial Library in Shreveport, La. Contributions of books and periodicals are desired and should be sent to Mr. Harry Buchner, Carter Oil Co., Shreveport, Louisiana."

L. L. NETTLETON

FINANCIAL SUPPORT FOR AMERICAN GEOLOGICAL INSTITUTE

The Council of the Society of Exploration Geophysicsts, at its meeting in St. Louis on April 24, 1951, voted a contribution of one thousand dollars to the American Geological Institute. In his letter of transmittal which accompanied the society's check, President Hammer expressed hope that the contribution would help to continue the work of the AGI for the advancement of the geological sciences, and confidence that the accomplishments of the institute's first two years would bring even more important results in the future. Dr. Hammer further stated that the S.E.G. made this contribution as a member society in the A.G.I. on the basis of its present financial resources, and that the Council could not guarantee continued annual contributions of this nature, but that succeeding councils will give sympathetic consideration to the support of the institute.

ROUNDTABLE DISCUSSION ON SAFETY PROBLEMS

April 23, 1951, following the afternoon technical sessions of the Society of Exploration Geophysicists, a group of twenty-three members of the society interested in problems of safety and accident prevention met in Committee Room Six.

One of the topics discussed was the accident information exchange arrangement that has been in force for several months between Phillips Petroleum, Geophysical Service, Inc., Seismic Exploration, Inc., Seismograph Service Corporation, and United Geophysical Company, Inc. It was decided to keep this exchange on an independent basis, not affiliated with any group or the society. Participation is open to all companies interested. Information is exchanged on a confidential basis without the participant's identity mentioned in connection with information submitted.

It was also decided that safety and accident prevention roundtable discussions at future national or regional meetings would be very beneficial. Mr. Bart W. Sorge, as chairman of the discussion group, was instructed to request the society's approval so that safety roundtable discussions be included in the program of future meetings.

It was also decided that it would be an advantage to have the society appoint a temporary committee on safety. It would be this committee's function to cooperate with the American Petroleum Institute in matters pertaining to safety and accident prevention.

PERSONAL ITEMS

O. F. VAN BEVEREN has been promoted from exploration superintendent to assistant general manager of Standard Oil Co. of California's exploration department.

KLAAS VAN DER WEG has become chief geophysicist in the exploration department of General Petroleum Corp., 612 S. Flower St., Los Angeles 14, Calif.

HARVEY CASH, JR. has been promoted to assistant division manager, Oklahoma division, The Texas Company producing department.

HERMAN S. SIMMONS, well known in the geophysical industry as sales manager of Herb J. Hawthorne, Inc., Houston, died suddenly of a heart ailment while in Shreveport last March 6 on business.

STEWART BARCLAY has been promoted from chief geologist to chief geophysicist for Mexican Independent Oil Company, Mexico City.

JACK MARTIN, Supervisor for General Geophysical Co., has been transferred from Casper to Houston.

LEONARD J. LARGUIER has been transferred to Casper, Wyoming as area geophysicist for Standard Oil Company of Ohio.

GLEN W. LEDINGHAM has become manager of exploration for Western Gulf Oil Co., Los Angeles.

GORDON KIRBY has resigned from Petty Geophysical Engineering Co. to become Rocky Mountain geologist for Murphy Corp., Denver.

W. B. AGOCS, Professor of Physics at The University of Tulsa, is working temporarily on a magnetics program in the eastern United States.

JOHN W. STANFIELD, president of Industrial Electronics Supply Company, announces removal of the company's Dallas store to its new building at 134 Leslie Street. Industrial Electronics took over the Dallas and Tulsa stores of Harrison Equipment Company in 1950.

ODELL C. OLSON, petroleum geologist, has opened a consulting office at Antlers, southeastern Oklahoma. He was previously with Fred M. Manning, Inc.

ROBERT E. SHALLER has been appointed party chief of Geophysical Service, Inc. at Peace River, Alberta, Canada. E. R. HOLM has rejoined the company after obtaining his Master's degree in geology at Columbia University, and is now party chief of a crew in Wyoming. ROBERT W. GUIPRE has been promoted to party chief of a crew at Laredo, Texas. PAUL V. HODGE has been appointed as supervisor in the West Coast division, with office at 1107 Truxton Avenue, Bakersfield, California.

FONDREN LIBRARY on the Southern Methodist University campus has been established as a depository for geophysical publications which will be made available to geophysicists of the Dallas, Texas, area. Initial funds for purchase of geophysical publications to be deposited in the library have been given by the DALLAS GEOPHYSICAL SOCIETY.

GEORGE G. SHOR, JR., party chief for Seismic Explorations, Inc., has taken a leave of absence to return to the California Institute of Technology to complete the requirements for a Ph.D. in Geophysics.

L. DON LEET has become chairman of the Department of Geology and Geography and chairman of the Division of Geological Sciences at Harvard University, succeeding Marland P. Billings.

SHELL GRANTS FOR FUNDAMENTAL RESEARCH AND GRADUATE FELLOWSHIPS RENEWED FOR 1951–52

The Shell organization's programs in support of higher education have been renewed for the academic year 1951–52, the Shell Fellowship Committee announced today. A series of Fundamental Research Grants, initiated last year, will be extended for a second year and will total $60,000. The new research grants supplement Shell's Graduate Fellowship Program of 45 fellowships, totaling $75,000 annually, which also remains unchanged for 1951–52.

Under the program of Fundamental Research Grants, direct awards are made to university science departments to assist them in conducting basic research. Twelve grants of $5,000 each have been made in the fields of Chemistry, Chemical Engineering, Geology, Mechanical Engineering, Metallurgy-Corrosion, and Physics. Schools receiving these awards are: California Institute of Technology, Carnegie Institute of Technology, University of Chicago, Harvard, Massachusetts Institute of Technology, Princeton, Stanford, and Yale. There are no restrictions on publication and use of the results, nor on the way the money is spent provided it is utilized directly for fundamental research in the field designated.

The idea of grants by industry for basic research is relatively new and gives recognition to the vital importance of this type of research for continued progress in industry and national defense. This concept also recognizes that the colleges are well equipped to carry on such research and that, without outside aid, they are often unable to undertake the work that should be done to promote the national welfare.

Shell's Graduate Fellowship Program is designed to assist outstanding students to obtain advanced scientific degrees. It provides for awards to universities in the fields of Chemistry, Chemical Engineering, Geology, Geophysics, Mechanical Engineering, Petroleum Production Engineering, Physics, and Plant Science.

Students recommended by the colleges as Shell Fellows receive a stipend of $1200 for the academic year. Their tuition and fees are paid, and a special fund of $300 is allocated to each school for related research expenses of the fellow. Candidates in their final year of Doctorate study are given preference but awards may be made to other graduate students. Recipients of these grants are under no obligation to Shell.

Both programs are administered by the Shell Fellowship Committee, a group of senior executives representing Shell Oil Company, Shell Chemical Corporation, Shell Development Company, and Shell Pipe Line Corporation.

SOCIETY OF EXPLORATION GEOPHYSICISTS

CONSTITUTION

Article I.	Name	Article X.	Meetings
Article II.	Object	Article XI.	Local Sections
Article III.	Membership	Article XII.	Districts
Article IV.	Code of Ethics	Article XIII.	Affiliated Societies
Article V.	Election, et cetera, of Members	Article XIV.	Committees
Article VI.	Officers	Article XV.	Business Manager
Article VII.	Duties of Officers	Article XVI.	Review by Members
Article VIII.	Council	Article XVII.	Bylaws
Article IX.	Executive Committee	Article XVIII.	Amendments to the Constitution

CONSTITUTION

(As amended to August 26, 1948)

Article I. Name

Section 1. The Society shall be called the "Society of Exploration Geophysicists."

Article II. Object

Section 1. The objects of this Society shall be to promote the science of geophysics especially as it relates to exploration and research, to foster the common scientific interests of geophysicists, and to maintain a high professional standing among its members.

Article III. Membership

Section 1. The membership of this Society shall consist of persons elected and qualified in accordance with the Constitution and Bylaws of this Society at the time of such election.

SECTION 2. The membership of this Society shall consist of Honorary Members, Active Members, Associate Members, and Student Members.

SECTION 3. To be eligible to election to Honorary Membership a person shall, in the unanimous opinion of the Standing Committee on Honors and Awards and the Council, have made a distinguished contribution to geophysics or a related field which warrants exceptional recognition.

SECTION 4. To be eligible to election to Active Membership an applicant must have been actively engaged in practising or teaching geophysics or a related field for not less than eight years (up to four years as a student in a recognized college or university may be counted toward this total) of which at least three years must have involved work of a responsible nature calling for independent judgment and the application of geophysical or geological principles.

SECTION 5. To be eligible to election to Associate Membership, an applicant must be actively interested in geophysics.

SECTION 6. To be eligible to election to Student Membership an applicant must be a graduate or undergraduate student in good standing in residence at a recognized university or college.

SECTION 7. An Honorary Member or Active Member shall enjoy all privileges of the Society. He shall be eligible to hold any office, to vote on all matters submitted to the membership, to petition the Council or Executive Committee on any matter, to sponsor applicants for membership and to publish his affiliation with the Society.

SECTION 8. An Associate Member or Student Member shall be entitled to attend the meetings of the Society, to receive its Journal and to purchase its publications, on the same terms as an Active Member. He shall have none of the other privileges of membership and in publishing his affiliation with the Society shall clearly indicate his grade of membership.

ARTICLE IV. CODE OF ETHICS

SECTION 1. Membership of any class shall be contingent upon conformance with the established principles of professional ethics.

ARTICLE V. ELECTION, RESIGNATION AND EXPULSION OF MEMBERS

SECTION 1. The method of election to the various grades of membership shall be as set forth in the Bylaws.

SECTION 2. Any member in good standing may resign from the Society at any time as set forth in the Bylaws.

SECTION 3. Any member may for the good of the Society be suspended or expelled from the Society at any time as set forth in the Bylaws.

ARTICLE VI. OFFICERS

Section 1. The officers of the Society shall be a President, a Vice-President, a Secretary-Treasurer, and an Editor. Officers shall be elected in the manner prescribed in the Bylaws for a term of one year with the exception of the Editor, whose term shall be two years.

SECTION 2. Election of officers shall be by secret mail ballot. On the ballot shall be printed the nominees for each office arranged in alphabetical order.

SECTION 3. The Standing Committee on Nominations shall nominate, in the manner prescribed in the Bylaws, two candidates for each office to be filled. Further nominations may be made by petition as set forth in the Bylaws.

SECTION 4. The officers shall assume the duties of their respective offices immediately after the close of the Annual Meeting following their election.

SECTION 5. No officer shall be eligible for election to the same office for two consecutive terms.

SECTION 6. In case of a vacancy in any office, other than the President's, the Executive Committee shall select a successor to serve until the close of the annual meeting following this appointment.

ARTICLE VII. DUTIES OF OFFICERS

SECTION 1. The President shall be the presiding officer at all the meetings of the Society, shall take

cognizance of the acts of the Society and of its officers, shall appoint such Standing Committees and special committees as are required for the purposes of the Society, and shall delegate members to represent the Society. He may, at his option, serve on, and may be chairman of, any committee. He shall prepare an address to be given before the members of the Society at the Annual Meeting.

SECTION 2. The Vice-President shall assume the office of President in case of a vacancy from any cause in that office and shall assume the duties of President in case of the absence or disability of the latter. He shall also be responsible for all National Meetings of the Society.

SECTION 3. The Secretary-Treasurer shall assume the duties of the President in case of the absence of both the President and Vice-President. He shall have charge of the financial affairs of the Society and shall annually submit reports as Secretary-Treasurer covering the fiscal year, which he shall arrange to have published in the next regular issue of the Journal of the Society. Under the direction of the Council, he shall arrange for the receipt and disbursal of all Society funds. He shall cause an audit to be prepared annually by a public accountant at the expense of the Society. He shall give a bond, and shall cause to be bonded, all employees to whom authority may be delegated to handle Society funds. The amount of such bonds shall be set by the Council and the expense shall be borne by the Society.

SECTION 4. The Editor shall be in charge of the editorial business, shall submit an annual report of such business, shall have authority to solicit papers and material for the regular Society publication and for special publications, and may accept or reject material offered for publication. He may appoint associate, regional, and special editors.

ARTICLE VIII. COUNCIL

SECTION 1. The Council of the Society shall consist of the officers, the Past President, the Past Prior President, and all elected District Representatives.

SECTION 2. The Council shall be the governing body of the Society and subject to the provisions of the Constitution and Bylaws shall have full control and management of the affairs and funds of the Society.

SECTION 3. A joint meeting of the outgoing and incoming Councils shall be held at the call and under the Chairmanship of the newly elected President during or within seven days after the Annual Meeting of the Society. At this joint meeting the Councils shall hear reports from all Officers and Committees and review the activities of the Society for the past year. With the advice of the outgoing Council, the incoming Council shall conduct any necessary business and issue instructions or recommendations to any officer or committee, subject to the provisions of the Constitution and Bylaws. All committee chairmen shall attend this meeting, but, as Chairmen, shall have no vote.

SECTION 4. At the call of the President or a majority of the Council members, and after written notice to all Council members, the Council may meet at any time.

SECTION 5. A quorum at any meeting of the Council shall consist of six Council members.

SECTION 6. Unless otherwise provided by the Constitution, all actions by the Council shall require a majority vote of the members present.

ARTICLE IX. EXECUTIVE COMMITTEE

SECTION 1. The Executive Committee shall consist of the President, the Vice-President, the Secretary-Treasurer, the Editor, and the Past President.

SECTION 2. When the Council is not in session the Executive Committee shall have full authority, subject only to prior instructions by the Council, to exercise all powers of the Council.

SECTION 3. All actions of the Executive Committee shall require a majority vote of all members of the Committee.

SECTION 4. The Executive Committee may vote on any matter either by mail or in person.

ARTICLE X. MEETINGS

SECTION. 1. The Society shall hold at least one meeting of the members each year, this meeting to be known as the Annual Meeting. One session of this meeting shall be a Business Meeting, at which

reports of the Officers and Committees shall be read and the result of the mail ballot for officers announced.

SECTION 2. The Annual Meeting shall be held at a time and place designated by the Executive Committee.

SECTION 3. Additional meetings of the Society may be called by the Executive Committee.

ARTICLE XI. LOCAL SECTIONS

SECTION 1. Local sections, consisting of members of the Society and other persons engaged in geophysics or a related field residing within an appropriate distance of a central point, may be organized as provided in the Bylaws.

SECTION 2. Each local section shall assist in carrying out the objectives of the Society within the territory assigned to the section by the Council.

SECTION 3. Each local section shall have one district representative if among its members there are less than seventy-five Honorary Members and Active members of the Society in good standing, two district representatives if more than seventy-five and less than one hundred fifty, or three district representatives if more than one hundred fifty.

SECTION 4. The district representatives shall be elected from among the Honorary Members and Active Members of the Society in good standing for terms stated and in the manner prescribed in the Bylaws and shall not be eligible for two consecutive terms.

ARTICLE XII. DISTRICTS

SECTION 1. The Council shall divide the area of the continental United States, not assigned to local sections, into not more than seven districts. Council may designate districts outside the area of the continental United States.

SECTION 2. Each district shall have for each seventy-five Active members of the Society, who are not members of a local section, one district representative, who shall be appointed by the President for a term of one year expiring at the close of the Annual Meeting.

ARTICLE XIII. AFFILIATED SOCIETIES

SECTION 1. The Council may arrange for affiliation of the Society with any duly organized groups or societies.

SECTION 2. The terms of affiliation must provide that the Society shall have the right to dissolve such affiliation at any time, subject only to the payment of any sums it may legally owe the affiliated group or society.

ARTICLE XIV. COMMITTEES

SECTION 1. In addition to the Executive Committee, there shall be appointed Standing Committees to further the purposes of the Society.

SECTION 2. The duties of the Standing Committees and the method of their appointment shall be in accordance with the Bylaws.

SECTION 3. The President may at any time appoint Special Committees for such purposes as he may deem fit.

SECTION 4. The terms of all Special Committees shall expire at the close of the Annual Meeting following their appointment.

ARTICLE XV. BUSINESS MANAGER

SECTION 1. The Council may employ a Business Manager for the Society and pay him such salary and other compensations from the Society's funds as they deem advisable.

SECTION 2. The Business Manager shall provide a bond appropriate in amount, the cost to be borne by the Society.

SECTION 3. The Business Manager shall, under the supervision of the Secretary-Treasurer, perform such duties as the Council may assign him.

SECTION 4. The Council may discharge the Business Manager at any time.

Article XVI. Review by Members

Section 1. All acts of the Officers, Council, and Committees of the Society shall be subject to review by the members.

Section 2. Proposals to change any decision, policy or procedure of any Officer, the Council, or any Committee shall be submitted in writing to the President and signed by at least twenty-five Honorary and Active Members in good standing.

Section 3. Upon receipt of such a petition with a sufficient number of valid signatures, the President shall advise the Council and the Officer or Committee involved.

Section 4. Should the Officer or Committee involved be unwilling to comply with the petition, it, together with a discussion by the proposer and the Officer or Committee involved, shall be published in the next issue of the Society's Journal.

Section 5. Within thirty days after publication in the Journal, the petition shall be submitted to the membership by mail ballot by the President. A majority of the ballots returned within thirty days after being mailed by the President shall be decisive. Should the vote favor the petition, it shall be complied with, within the limitations imposed by the Constitution and Bylaws, as promptly as practicable.

Article XVII. Bylaws

Section 1. The Council shall make such Bylaws not in conflict with the Constitution, as it may deem necessary for the proper government of the Society. The Council may amend the Bylaws at the annual joint meeting by an affirmative vote of two-thirds of the members of the incoming Council present. All proposed amendments must, however, be published in the Society's Journal before being submitted to the Council.

Article XVIII. Amendments to the Constitution

Section 1. Amendments to this Constitution may be proposed by any ten members of the Society, by any Officer of the Society, or by a Constitutional Committee appointed by the President.

Section 2. Any proposed amendment shall be submitted to the President in time for publication in the Society's Journal prior to the Annual Meeting.

Section 3. At the annual joint meeting of the Council, all proposed amendments received since the previous annual meeting, shall be considered. Those receiving approval from a majority of the members of the incoming Council present shall be submitted by mail ballot, arranged by the Secretary-Treasurer, to the entire membership of the Society within sixty days. If a majority of the ballots returned within sixty days of their mailing favor the proposed amendment, it shall become effective at the expiration of this sixty days. All amendments shall be reported in the Society's Journal.

BYLAWS

Article I. Publications
Article II. Election of Honorary Members
Article III. Election of Active, Associate and Student Members
Article IV. Dues
Article V. Resignation of Members
Article VI. Expulsion of Members
Article VII. Election of Officers
Article VIII. Local Sections
Article IX. Finances of Local Sections
Article X. Standing Committees

BYLAWS

Article I. Publications

Section 1. The Society shall publish a Journal entitled *Geophysics*.

Section 2. The Journal shall be published at intervals designated by the Executive Committee.

Section 3. All reports to the Society by its officers and committees shall be published in the Journal. All members of the Society shall be presumed to have due notice of all Society matters published in the Journal. Each issue shall contain a membership list of all Standing and Special Committees.

SECTION 4. Original papers, reviews, abstracts, notes or letters containing information deemed by the Editor to be of interest to the members of the Society shall be published in the Journal. The Editor shall be the sole judge of whether such material is to be published.

SECTION 5. The subscription rate of the Journal shall be $9.00 ($9.50 foreign) per year to non-members and $3.00 per year to members. The first $3.00 of the annual dues of each dues paying member shall be set aside for the payment of his subscription to the Journal. Members of affiliated Societies shall be entitled to receive the Journal upon payment of a fee equivalent to the dues charged to an associate member.

SECTION 6. The Council may at its annual joint meeting authorize the printing of special publications to be financed and distributed in a manner approved by the Council.

ARTICLE II. ELECTION OF HONORARY MEMBERS

SECTION 1. The Standing Committee on Honors and Awards may submit to the President ninety days before the Annual Meeting the names of any person or persons they deem eligible to election as an Honorary Member. Their report shall explain the basis of their recommendation.

SECTION 2. The President shall submit copies of any such reports to all members of the Council not less than sixty days before the Annual Meeting.

SECTION 3. The Council members shall consider all such reports and vote by mail thirty days before the Annual Meeting. Unanimous action by those voting shall be required to elect any person as an Honorary Member.

ARTICLE III. ELECTION TO ACTIVE, ASSOCIATE AND STUDENT MEMBERSHIP

SECTION 1. An applicant for election to Active, Associate or Student Membership shall submit to the Business Manager of the Society an application setting forth in detail his education and experience. The application shall list the names and present addresses of persons who can verify the statements given therein. It shall list not less than three Active Members or Honorary Members of the Society, in good standing, who are personally acquainted with the training or experience of the applicant. This application shall be open to inspection at any time.

SECTION 2. The Executive Committee may waive the requirement of references from members of the Society for geographical or other reasons, if the applicant is otherwise eligible and furnishes other satisfactory references.

SECTION 3. The Business Manager shall write to all references for verification of the applicant's statements. All replies from references shall be considered confidential and shall not be disclosed except to the Executive Committee, without the references' prior written consent.

SECTION 4. The Business Manager, upon receipt of the replies from all references, shall submit to the Executive Committee the application and the replies from the references.

SECTION 5. Should the Executive Committee unanimously approve and sign the application, the applicant's name shall be published in the next regular issue of the Society's Journal for approval by the membership at large. If no objection to his election is received by the President within thirty days after this publication, he shall be pronounced elected. The Business Manager will notify the applicant. In the case of applicants for Student Membership publication is not required. The student member shall be pronounced elected when approved by the Secretary-Treasurer.

SECTION 6. An applicant for membership, upon being notified in writing of his election, shall pay full dues for the current year and upon making payment shall receive a membership card and the regular Society publications for the year of entrance. Unless payment of dues is made within thirty days by those living within the continental United States and within ninety days by those living elsewhere, the Executive Committee may rescind the election of the applicant.

SECTION 7. An Associate or Student Member may seek transfer to Active Membership by supplying added information to show that he has become eligible to election to Active Membership. The transfer shall be handled in the same manner as election to Active Membership. The Standing Committee on Membership may of its own initiative secure the necessary added information and submit it to the Executive Committee.

Article IV. Dues

Section 1. Honorary members shall not be required to pay dues and shall receive the Journal and other publications without charge.

Section 2. The annual dues of an Active or Associate Member of the Society shall be seven dollars and fifty cents ($7.50), which includes the cost of one subscription to the Society's Journal.

Section 3. The annual dues of a Student Member of the Society shall be four dollars and fifty cents ($4.50), which includes the cost of one subscription to the Society's Journal.

Section 4. Annual dues shall be payable in advance on January 1 of the calendar year. A bill shall be mailed to each Active, Associate or Student Member before that date, stating the amount of annual dues and the penalty for default. The Society's Journal shall be withheld from members pending payment of dues, and Active Members failing to pay by ten days prior to the Annual Meeting shall have their votes in the annual mail ballot disqualified. Members in arrears shall lose all privileges of membership until such arrears are met.

Article V. Resignation of Members

Section 1. Any member of the Society may resign at any time. Such resignation shall be submitted in writing to the Council.

Section 2. Any member who resigns under the provisions of Section 1 of this Article ceases to have any rights in the Society and ceases to incur further indebtedness to the Society.

Section 3. Any person who has ceased to be a member under Section 1 of this Article may be reinstated by unanimous vote of the Executive Committee subject to the payment of any outstanding dues and obligations which were incurred prior to the date when he ceased to be a member of the Society.

Article VI. Expulsion of Members

Section 1. Any member more than two years in arrears shall be dropped from the Society by the Executive Committee.

Section 2. Any member who is dropped under the provisions of Section 1 of this Article ceases to have any rights in the Society and ceases to incur further indebtedness to the Society.

Section 3. Any person who has ceased to be a member under Section 1 of this Article may be reinstated by unanimous vote of the Executive Committee subject to the payment of any outstanding dues and obligations which were incurred prior to the date when he ceased to be a member of the Society.

Section 4. Any member who, after being granted a hearing by the Executive Committee, shall be found guilty of a violation of the established principles of professional ethics, or shall be found guilty of having made a false or misleading statement in his application for membership in the Society, shall be asked to resign from the Society by unanimous vote of the Executive Committee. The decision of the Executive Committee in all matters pertaining to the interpretation and execution of the provisions of this section shall be final.

Article VII. Election of Officers

Section 1. The Standing Committee on Nominations shall consist of the President, the Past President, and the Prior Past President.

Section 2. The Standing Committee on Nominations shall nominate two or more candidates for each office to be filled. They must secure the consent of all candidates nominated.

Section 3. The Standing Committee on Nominations must submit their ticket to the President in time for publication in the October issue of the Society's Journal.

Section 4. For six weeks after the mailing date of the October issue of the Society's Journal, nominations in writing, signed by at least twenty Honorary Members or Active Members in good standing and accompanied by the written consent of the candidate, may be submitted to the President.

SECTION 5. At the expiration of the aforesaid six weeks period, the Business Manager will prepare and mail to each member, eligible to vote, a ballot listing all candidates properly nominated for each office. The candidates shall be listed alphabetically. With each ballot, the Business Manager shall send an official envelope having the member's name typed on the back.

SECTION 6. Each member voting shall cast one vote for each officer and shall return his ballot to the Business Manager in the official envelope carrying on the outside the written signature of the member submitting the ballot. Only ballots so prepared by members in good standing, and received by the Business Manager at his officially recognized address not later than ten days prior to the Annual Meeting shall be valid. The Business Manager shall indicate which ballots are valid and shall deliver the ballots unopened to the Standing Committee on Nominations for counting. The Standing Committee on Nominations shall appoint tellers to count the ballots prior to the Annual Business Meeting. The candidates receiving the greatest number of valid votes cast for an office shall be declared elected to that office. In case of a tie, the Standing Committee on Nominations shall decide by a secret vote which of the candidates shall be elected.

ARTICLE VIII. LOCAL SECTIONS

SECTION 1. Upon petition of twenty members in good standing residing within an appropriate distance of a central point, the Council may authorize the formation of a Local Section and assign a specific territory to the Local Section. The Council may decline to authorize the formation of a Local Section when in its judgment such an organization would not be compatible with the interests of the Society.

SECTION 2. In the organizing meeting of the Section, all members of the Society residing in the territory assigned by the Council to the Section shall be eligible to vote.

SECTION 3. The Section shall be known as "The (name of place) Section of the Society of Exploration Geophysicists."

SECTION 4. The principal work of a Section shall be the holding of regular meetings for the presentation and discussion of papers of interest to its members.

SECTION 5. The Section shall adopt Bylaws which must be approved by the Council of the Society and shall be consistent with the Constitution and Bylaws of the Society.

SECTION 6. The election of District Representatives by the Local Sections shall be by secret ballot. The term of office of a District Representative shall be two years; however, if the Section is entitled to more than one Representative, one of the Representatives elected at the establishment of the Section or added as the result of subsequent growth of the Section, shall be elected for a one year term if this is necessary to prevent the terms of all District Representatives from expiring simultaneously.

SECTION 7. District Representatives shall be elected at least three weeks prior to the Annual Meeting of the Society and shall take office at the close of the Annual Meeting.

SECTION 8. The Secretary of the Local Section shall submit to the Secretary-Treasurer of the Society a report of each meeting of the Local Section or its governing board within two weeks after the meeting. He shall submit to the Secretary-Treasurer of the Society the names of all officers and committee members within two weeks after their election or appointment.

SECTION 9. Any Local Section which for two consecutive years has among its membership fewer than twenty members in good standing of the Society shall automatically be dissolved by the Council at its annual joint meeting. The Council may at any time dissolve any Local Section for reasons it deems good and sufficient.

ARTICLE IX. FINANCES OF LOCAL SECTIONS

SECTION 1. The Society may, at the discretion of the Council, pay any portion of the necessary operating expenses of a Local Section up to the sum of the following amounts: (a) $100.00 per year; (b) $50.00 per meeting up to four meetings per year; (c) $0.50 per member of the Society.

SECTION 2. The Treasurer of the Local Section shall forward, from time to time, his application for such portions of the sum provided in Section 1 as may be needed to the Secretary-Treasurer of the

Society, who will arrange for the issuance of a check for the requested amount to the Treasurer of the Local Section.

SECTION 3. Prior to the Annual Meeting, the Treasurer of each Local Section shall transmit to the Secretary-Treasurer of the Society, for approval by the Council, an itemized statement of the expenditure of the funds received from the Society during the preceding calendar year.

SECTION 4. Allocations to a Local Section for the year in which it is established shall be in proportion to the fraction of the calendar year remaining.

SECTION 5. The Local Section may levy dues or raise funds in any other manner, subject to the approval of the Council. Payment of local dues shall, however, not be a prerequisite to participation in any activity financed wholly or in part with funds received from the Society.

ARTICLE X. STANDING COMMITTEES

SECTION 1. The Society shall have the following Standing Committees: (a) Standing Committee on Nominations; (b) Standing Committee on Membership; (c) Standing Committee on Honors and Awards; (d) Standing Committee on Publications; (e) Standing Committee on Program and Arrangements; (f) Standing Committee on Education; (g) Standing Committee on Student Membership; (h) Standing Committee on Distinguished Lectures; (i) Standing Committee on Radio Facilities; (j) Standing Committee on Reviews; (k) Standing Committee on Publicity; and (l) Standing Committee on Annual Survey of Geophysical Activity.

SECTION 2. Each Standing Committee shall have a chairman, appointed by the President unless otherwise specified in these Bylaws. The Chairman shall submit a report to the President of the Society at such intervals as the Chairman may deem advisable but at least quarterly. He shall submit to the Council at its annual joint meeting a report covering the activities of the Committee since the previous annual meeting.

SECTION 3. The Standing Committee on Nominations shall consist of the President who shall be chairman, the Past President, and the Past Prior President. Its duties shall be to nominate candidates for officers, to supervise counting the ballots and to declare the election of the officers as prescribed in Article VII of these Bylaws.

SECTION 4. The Standing Committee on Membership shall consist of three active members appointed for a period of one year by the President immediately following the Annual Meeting. One of the members appointed shall have been a member the preceding year. The Committee shall prescribe the manner of soliciting applicants for membership.

SECTION 5. The Standing Committee on Honors and Awards shall consist of five active members, none of whom shall have been members of the Society less than five years. The senior member of the Committee shall retire after the Annual Meeting. Vacancies shall be filled by the President. The Committee shall recommend candidates for election to Honorary Membership to the Council. The Committee shall recommend to the Council the establishment of Honors and Awards and shall recommend candidates for all established Honors and Awards of the Society to the Council.

SECTION 6. The Standing Committee on Publications shall consist of five active members who shall serve a two year term concurrent with the Editor and who shall be appointed by the Editor. The Committee shall have the duty of advising and assisting the Editor. The Editor shall appoint the Chairman of this Committee.

SECTION 7. The Standing Committee on Program and Arrangements shall consist of the Local Representatives plus three to ten additional active members appointed for a term of one year by the Vice-President, who shall be Chairman. The names of the members of the Committee shall be published in the July issue of the Society's Journal. The Committee shall have the duty of assisting the Vice-President in arranging and holding the Annual Meeting.

SECTION 8. The Standing Committee on Education shall consist of five active members appointed for one year by the President. The Committee shall promote effective geophysical education.

SECTION 9. The Standing Committee on Student Membership shall consist of five active members appointed for one year by the President. The Committee shall encourage the interest of students in geophysics and the Society.

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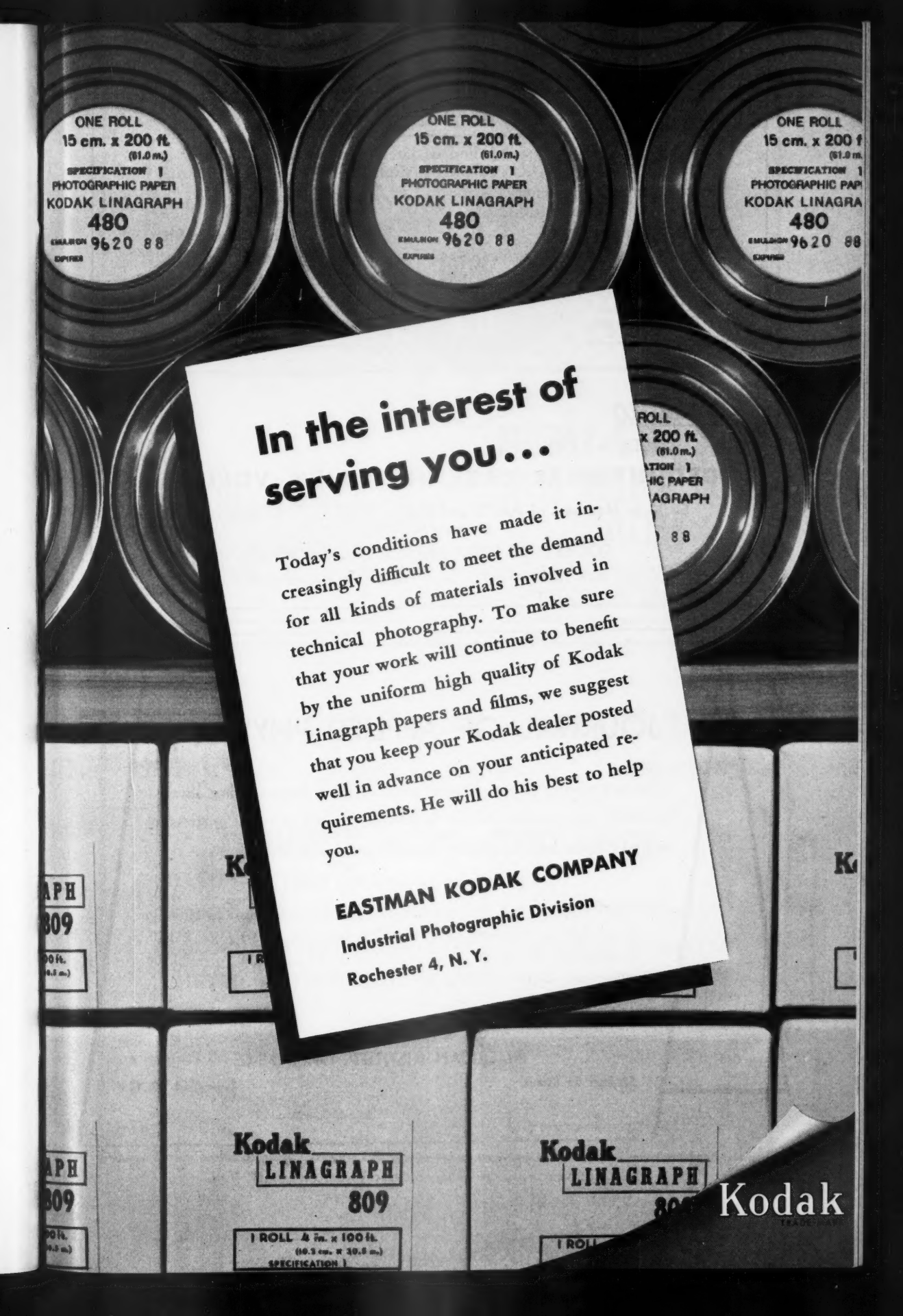
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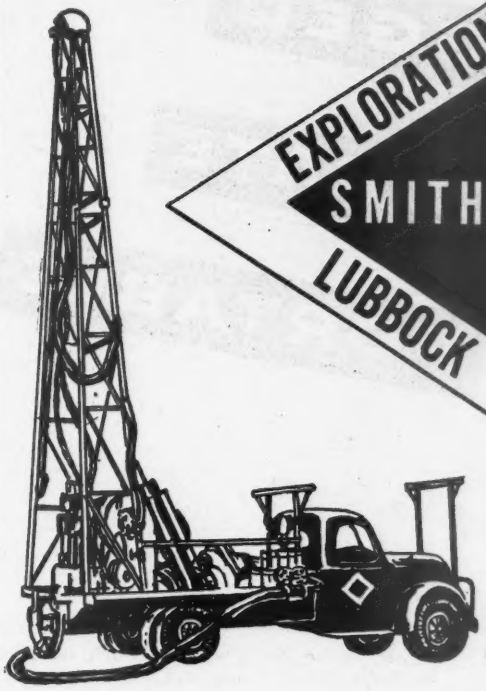

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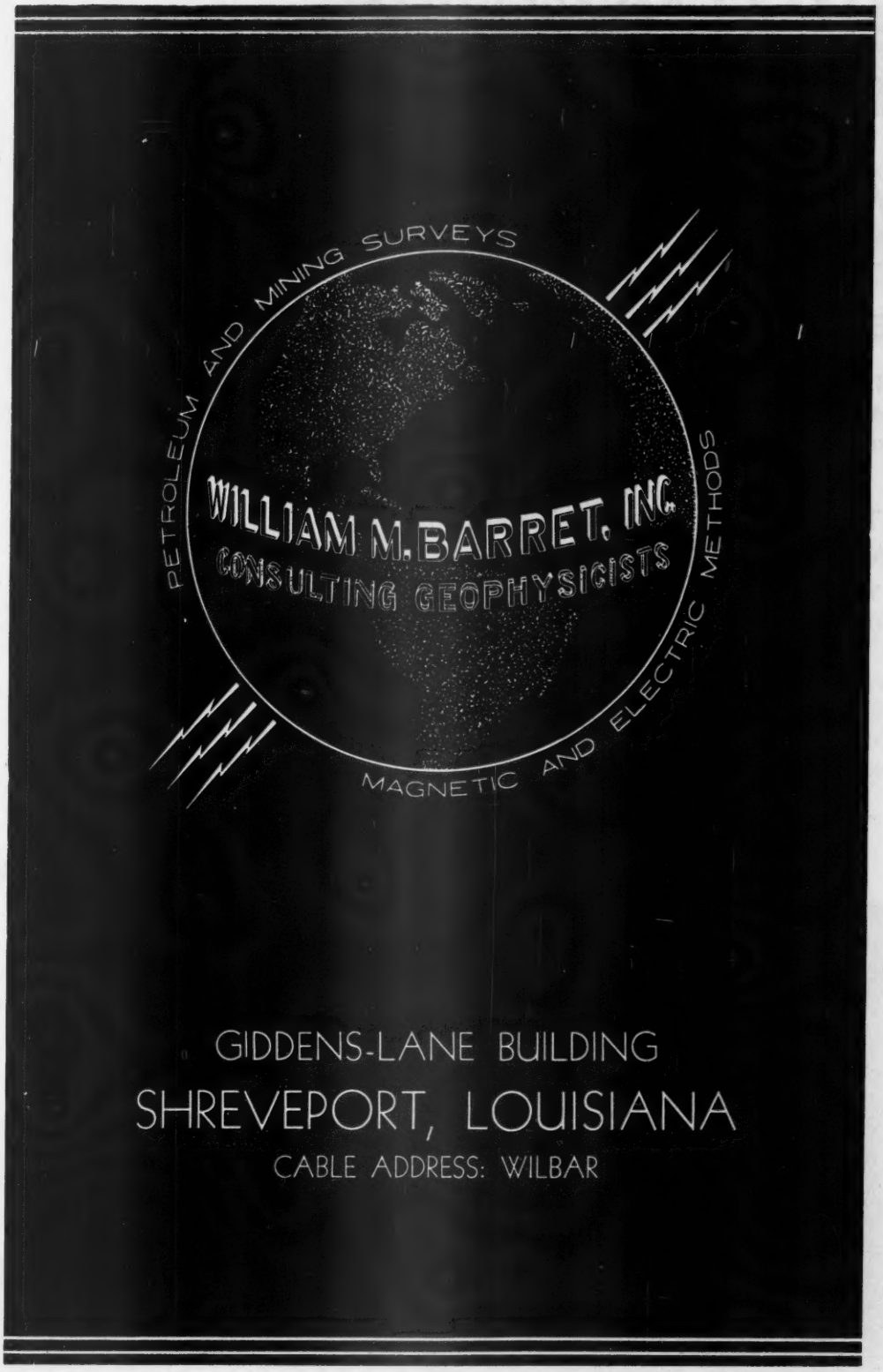
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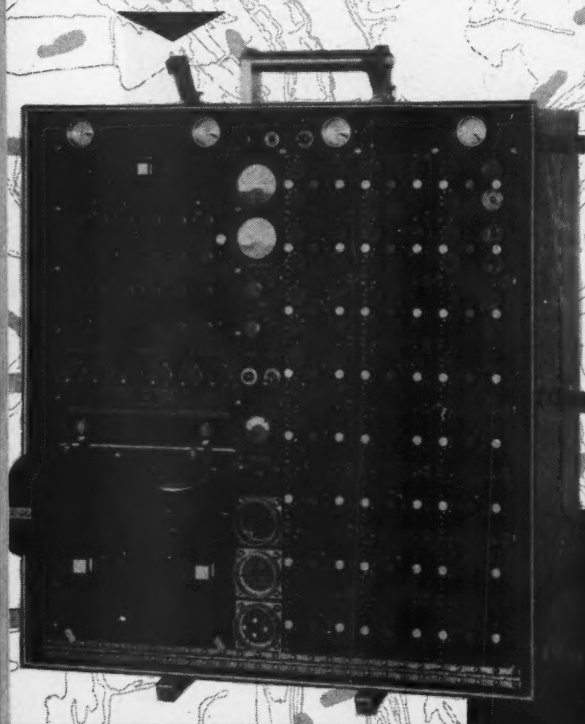

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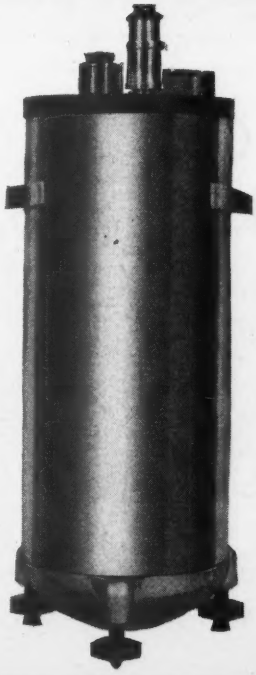

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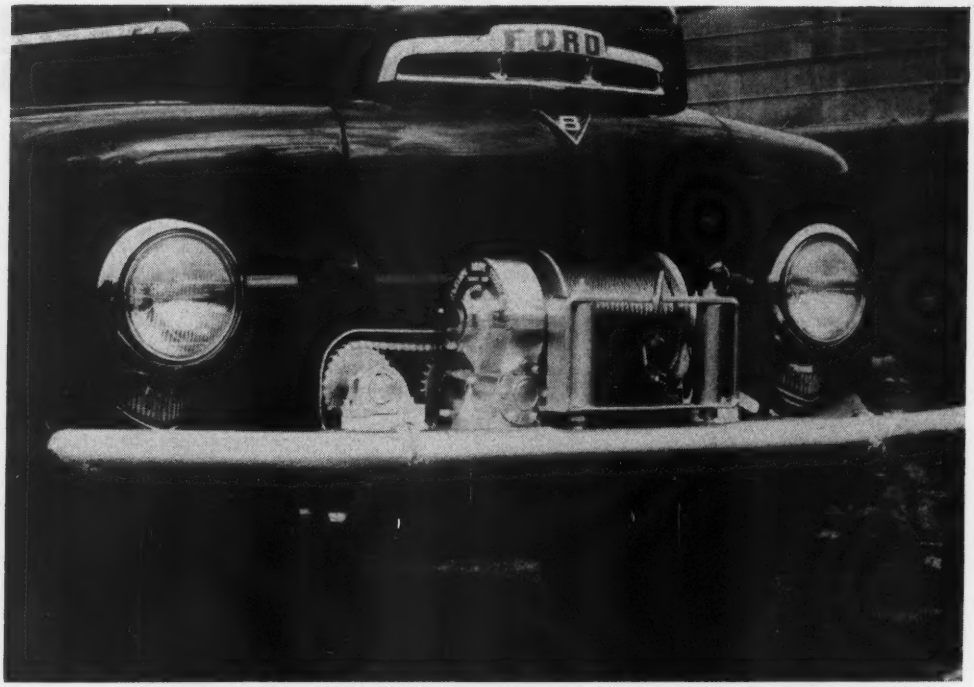

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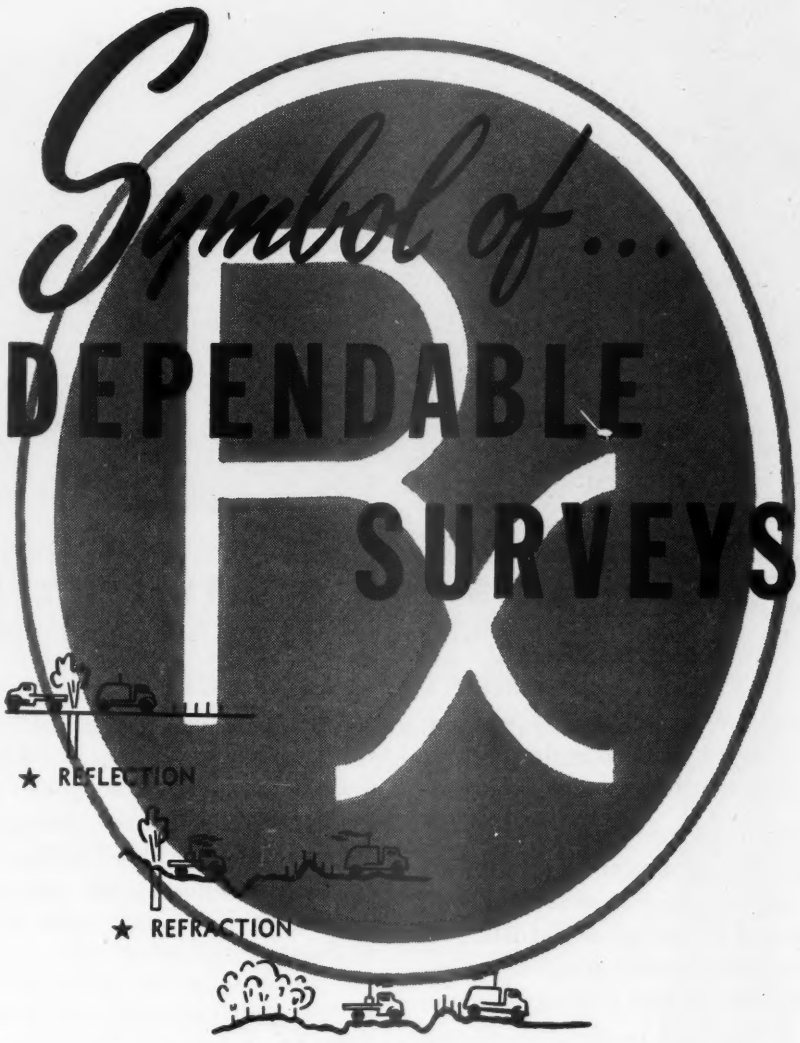

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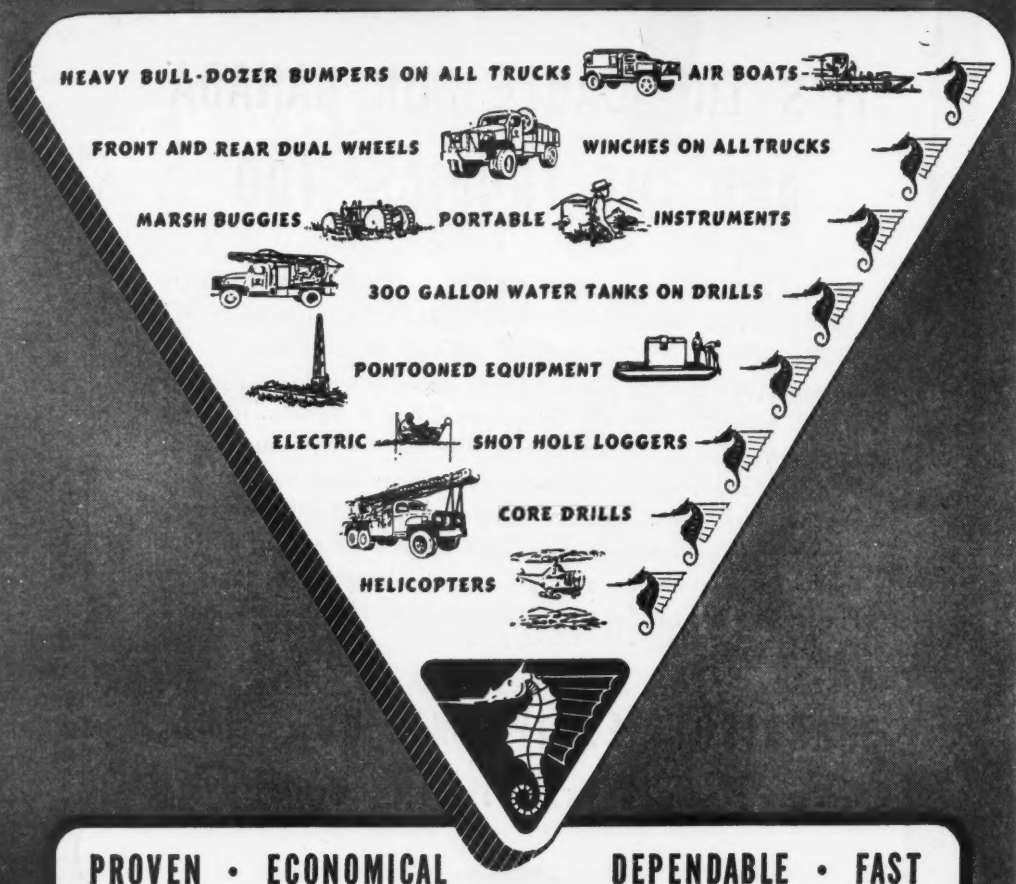

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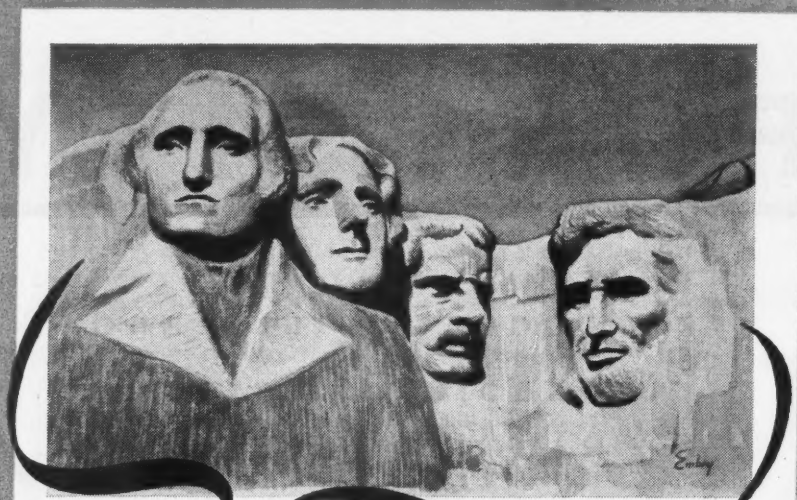

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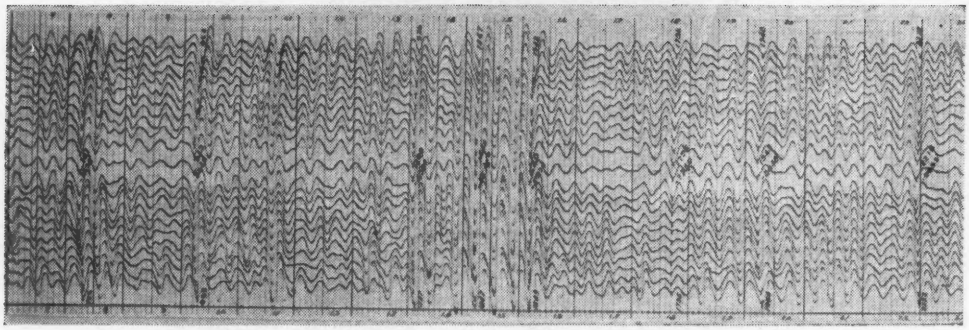

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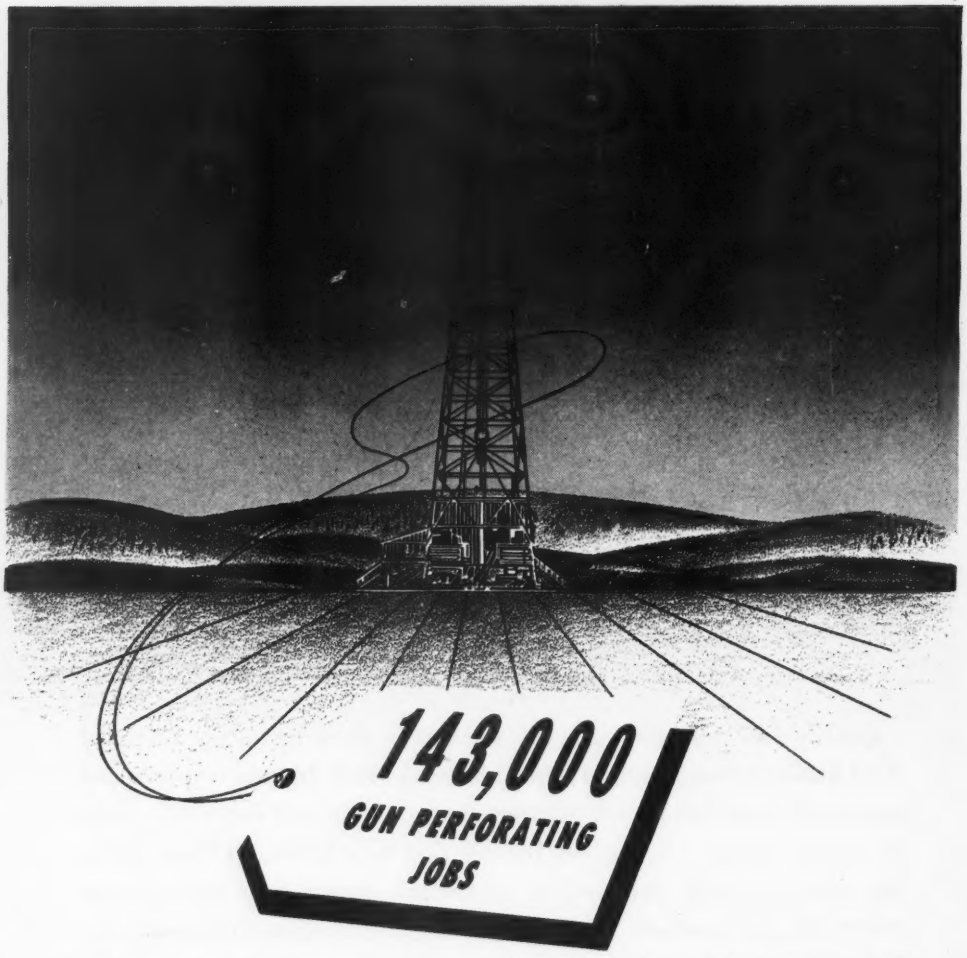

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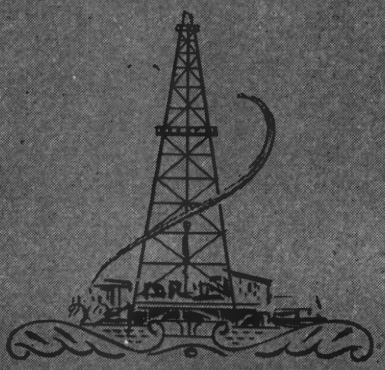

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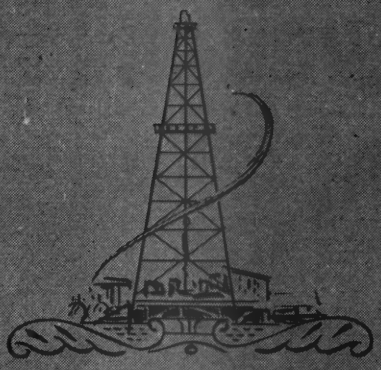

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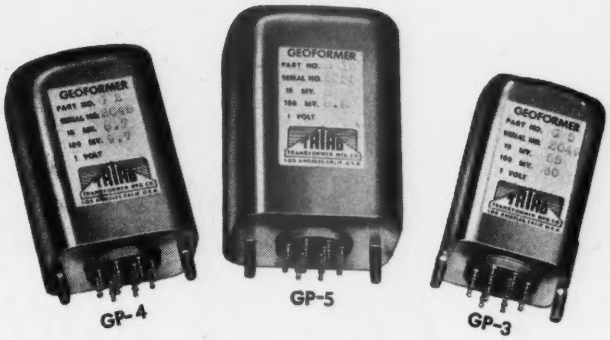

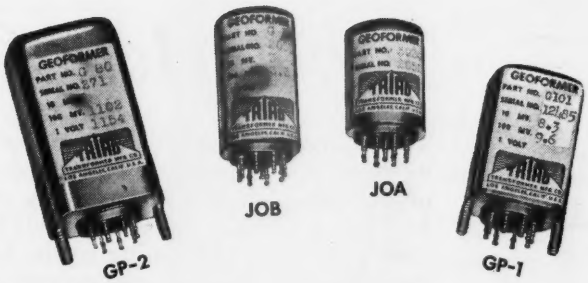

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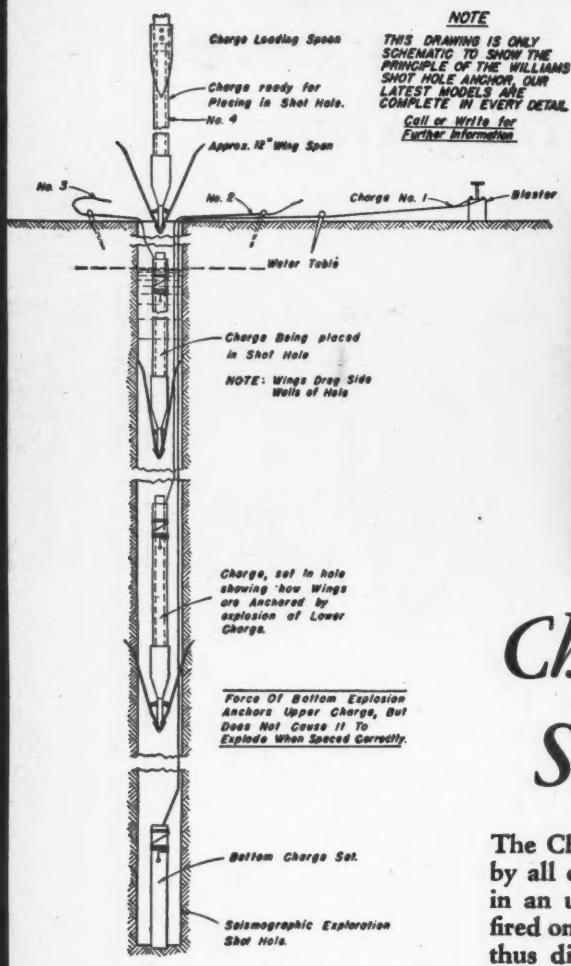
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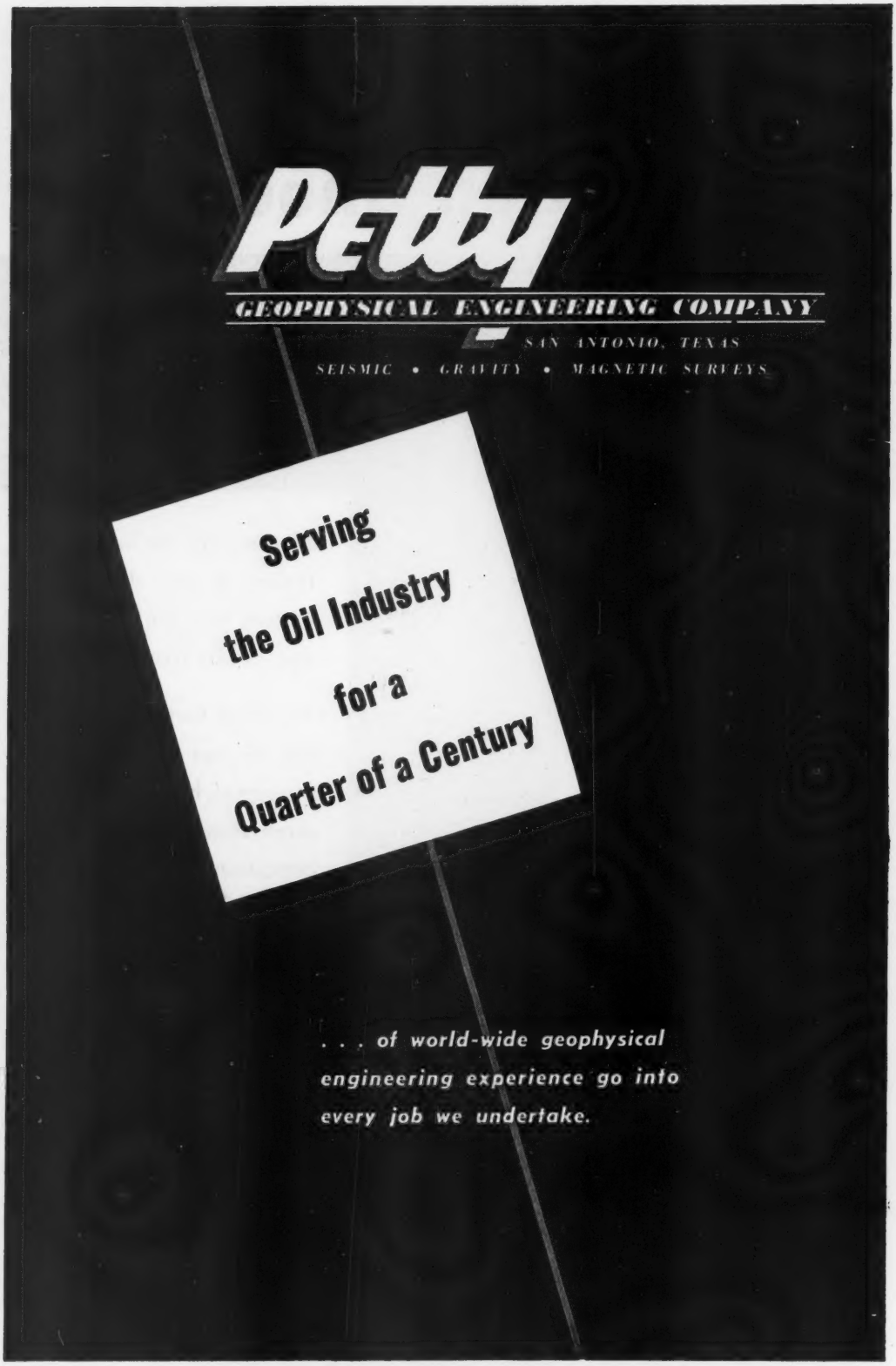
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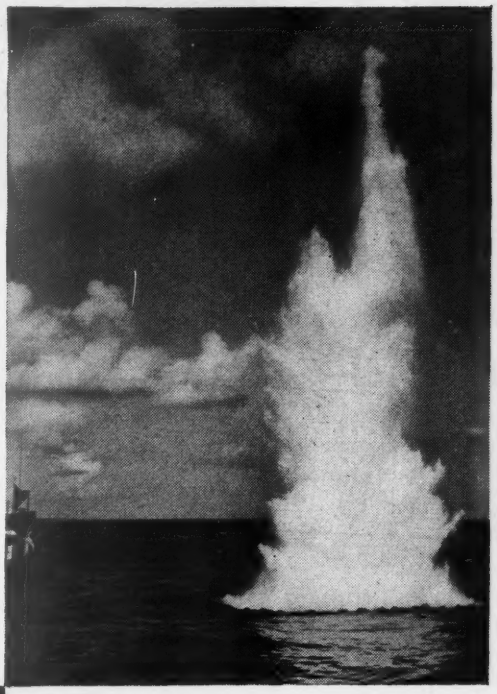

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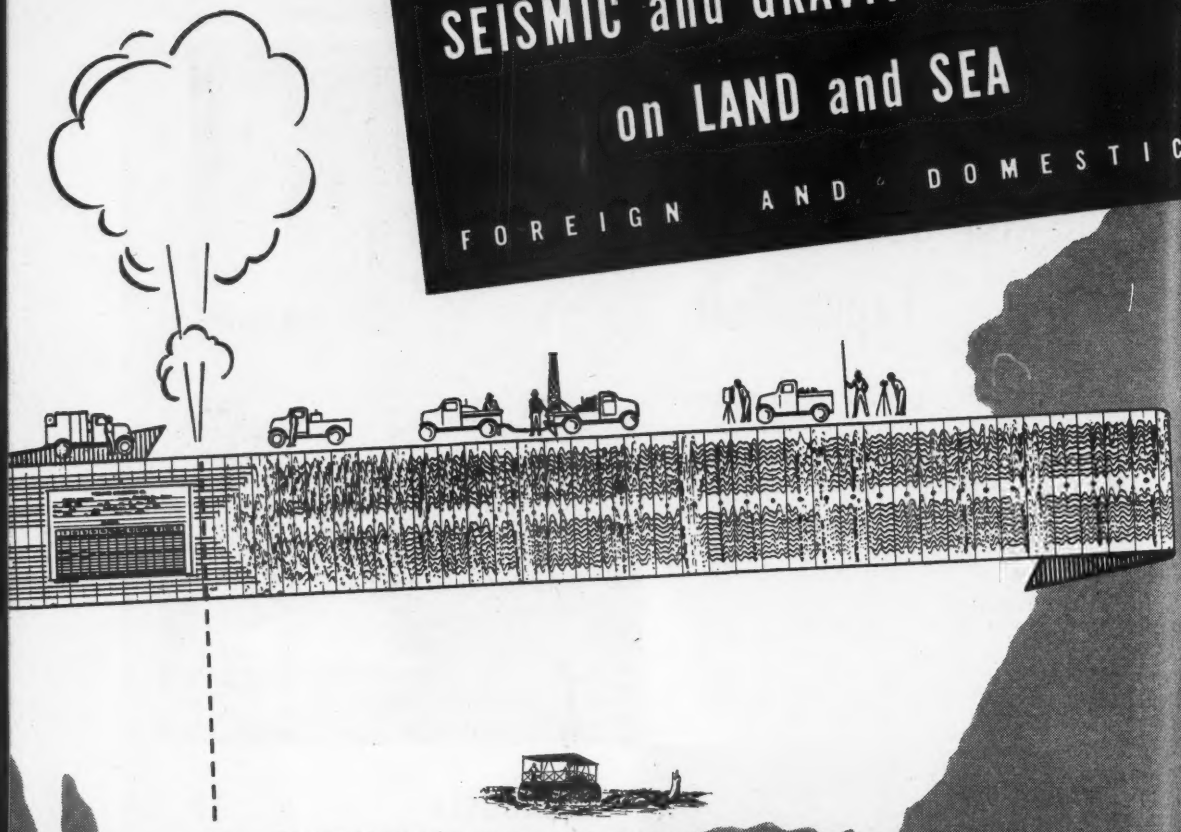

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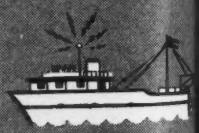

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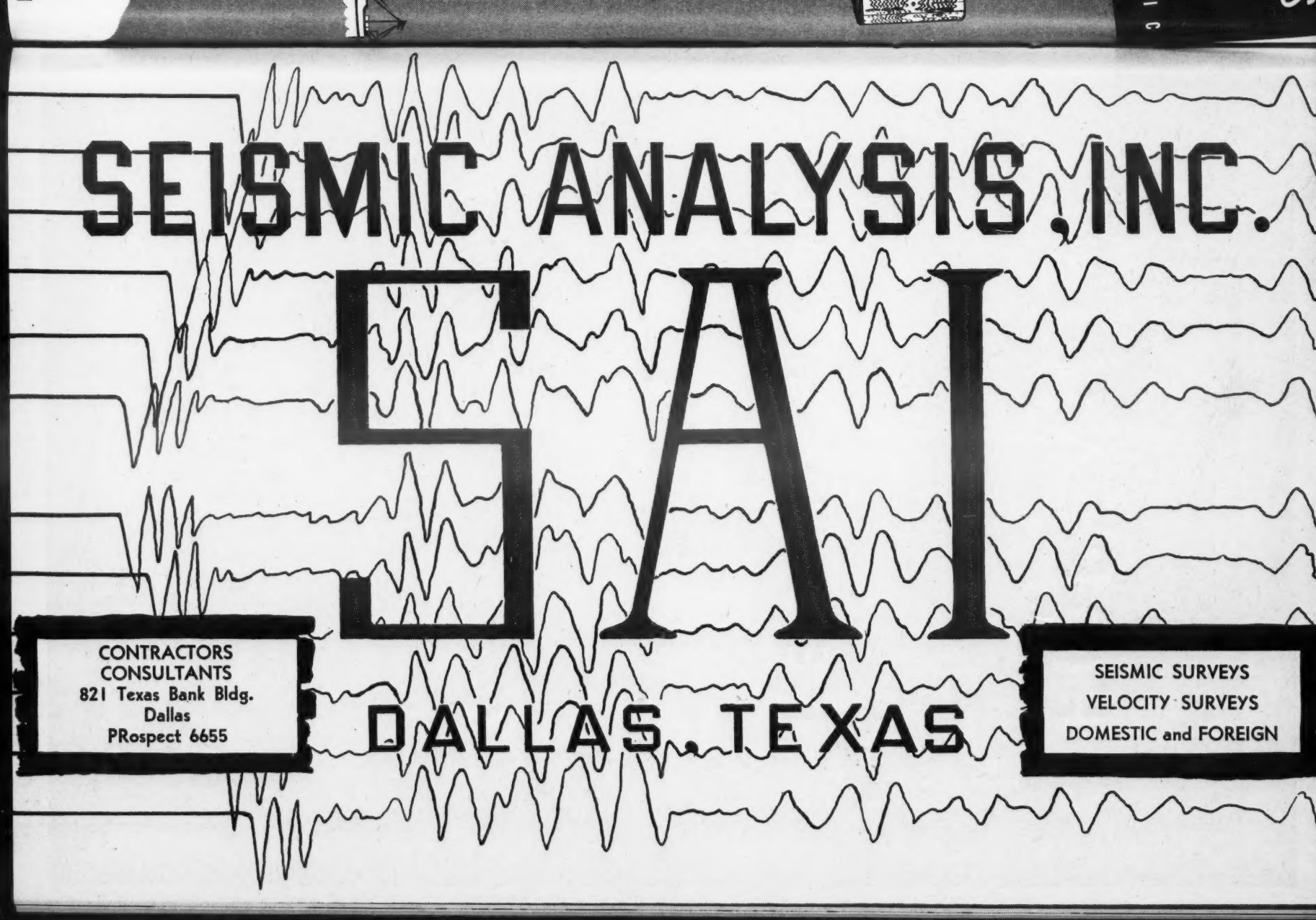
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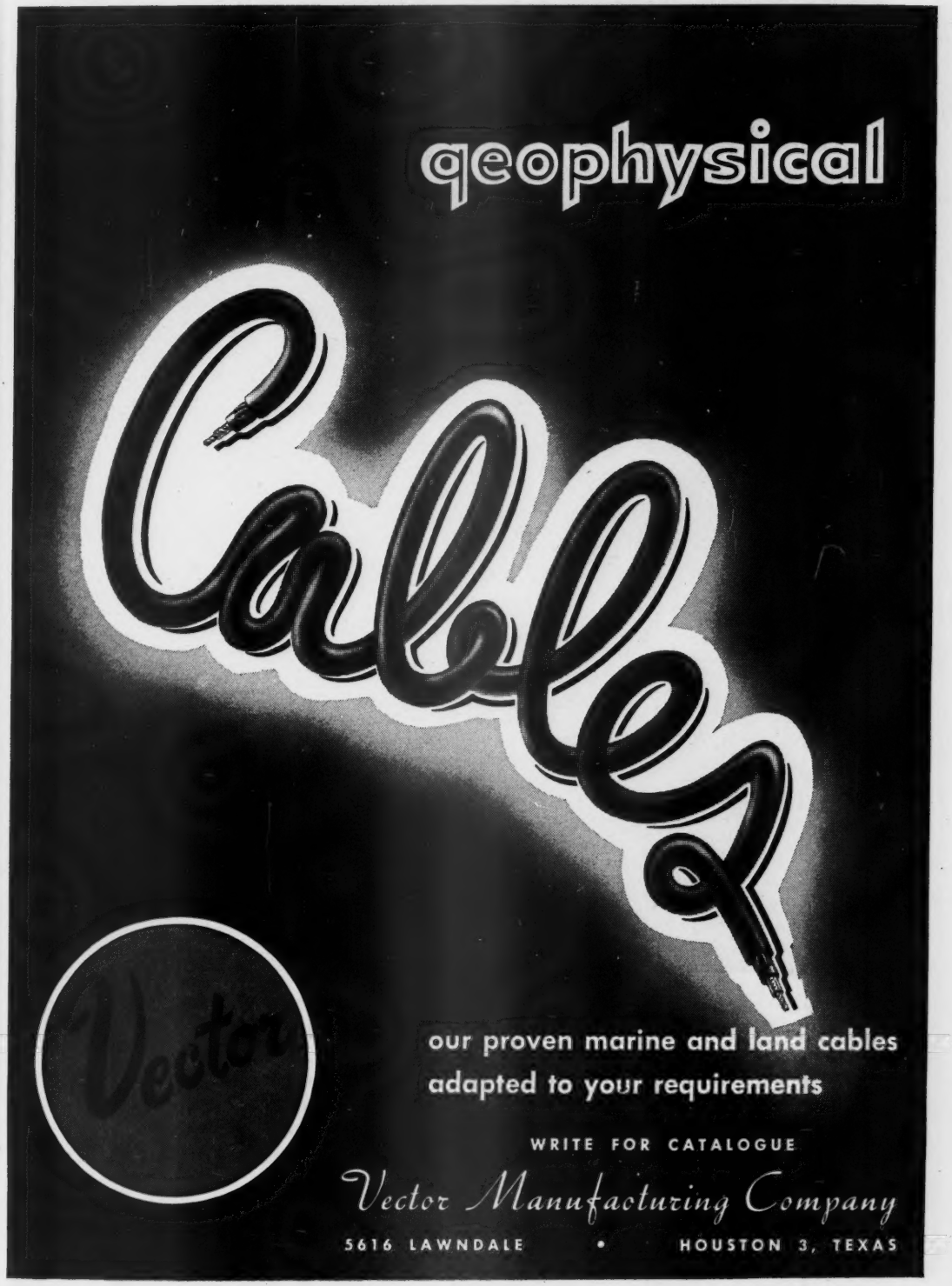
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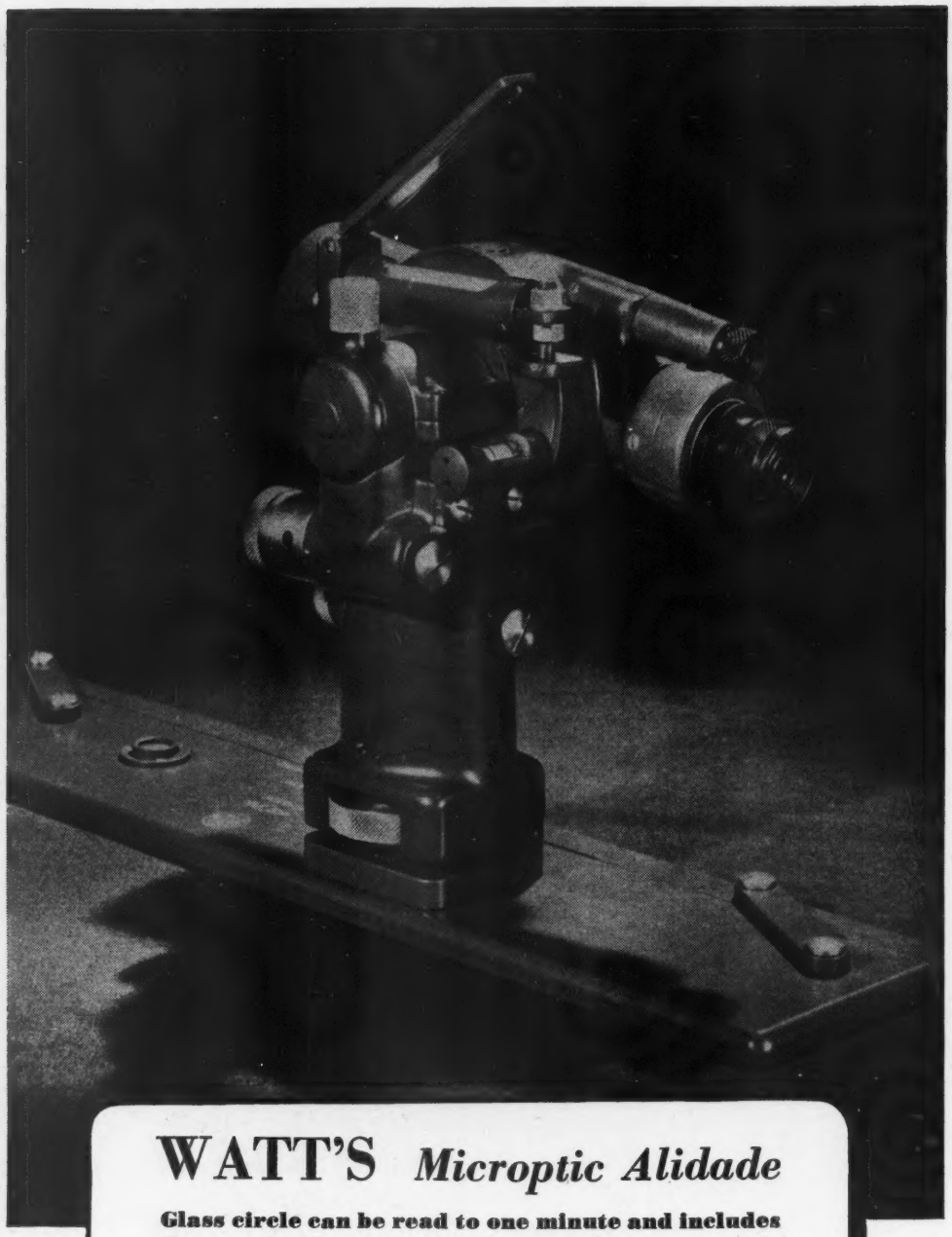

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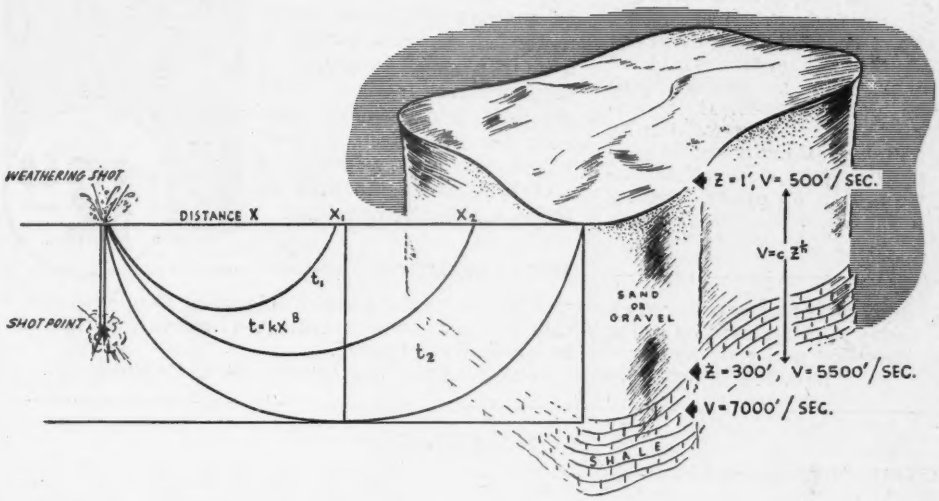

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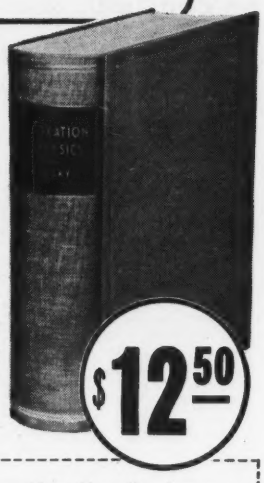

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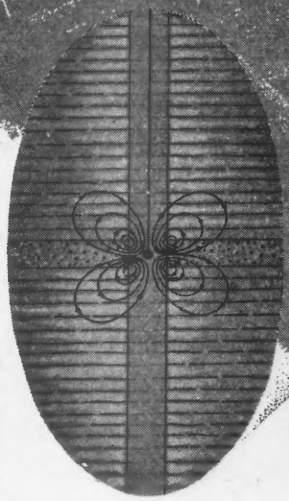

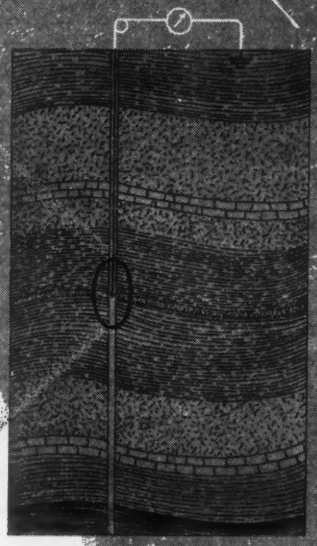

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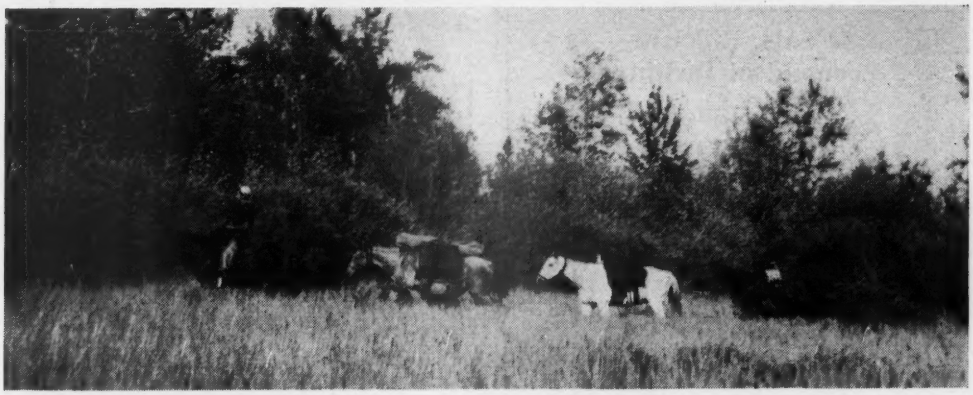

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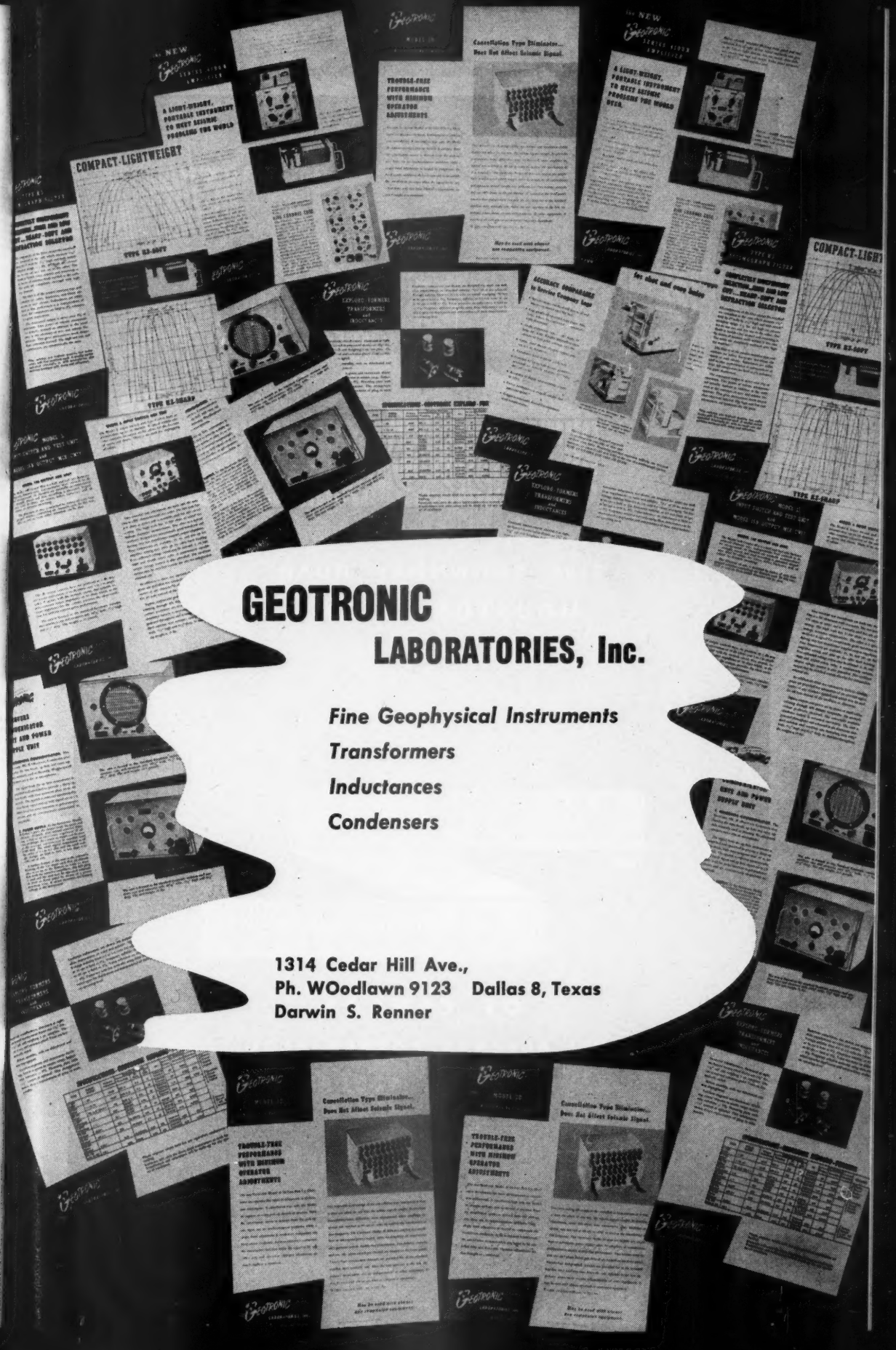
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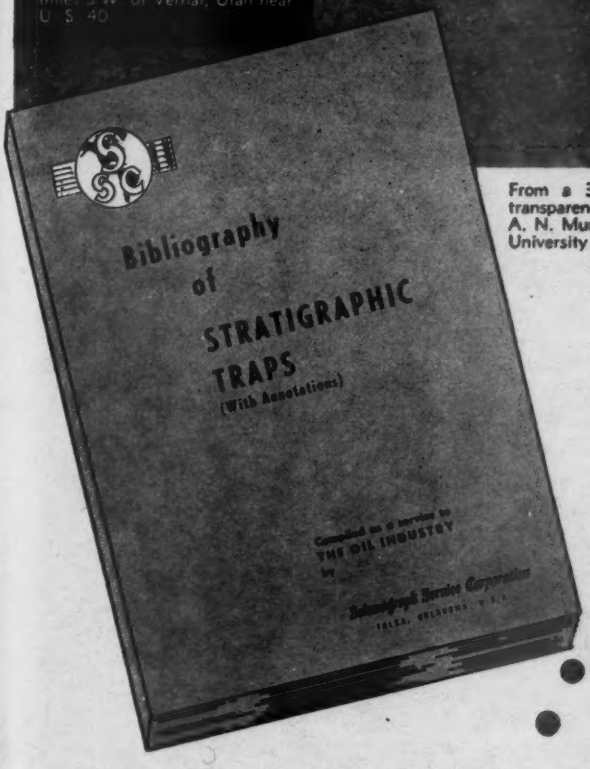

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Comdr. H. B. Jonnson
U. S. Navy

R. C. Pennell
U. S. Public Health Administration

AIR MAIL

April 3 1951

Mr. J. E. Jonesson
Vice-President
Geophysical Service, Inc.
6000 Lemmon Avenue
Dallas 9, Texas

Dear Mr. Jonesson:

On behalf of the National Committee, it is a pleasure to inform you that "Make No Mistake" was voted top honors in the Non-Theatrical Occupational Classification in the Safety Film Contest for films produced during 1950.

A record number of entries this year made the competition unusually keen, so your organization can be justly proud of having a winner.

Please accept our congratulations for a fine film and the contribution it makes in helping to prevent accidents.

A bronze plaque is being made up and you will be notified when it is finished - approximately six weeks. At that time also, we would like to make arrangements for a suitable time and occasion for presentation of this trophy.

Very cordially yours,

Wm. England
Secretary

WE:BG

P.S. The attached carbon is for Gulf Coast Films.

W. E.

This new color motion picture "Make No Mistake" is available for free showing . . . write for particulars

G S I

GEOPHYSICAL SERVICE INC.

6000 Lemmon Avenue • Dallas, Texas